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Visualization of the Battlefield: Final Technical Report

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BDM Federal, Inc.

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The Army is keenly aware of and preparing for a future that portends great change associated with land force dominance. A hallmark of the future battlefield will certainly be advanced technologies. Inordinate amounts of information in real and near-real time will be the rule not the exception. The new challenges for commanders are multi-dimensional. They are predicted on the need to integrate vast amounts of friendly and enemy information in short periods of time by covering large geographic areas quickly. The new Battle Dynamics include Battle Command, Battle Space, Depth and Simultaneous Attack and Early Entry.

Because of the greater complexity and the diversity of future operational environments, emerging systems and doctrine will incorporate: 1) networks for widely distributing information, 2) descriptive models that bring reliable clarity rather than uncertain predictions to the command environment, 3) flexible sharing of information and 4) command display systems capable of sending and receiving images and graphics while on the move.

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FINAL TECHNICAL REPORT

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FINAL TECHNICAL REPORT

CONTENTS PAGE

FINAL TECHNICAL REPORT

LIST OF TABLES | PAGE

LIST OF FIGURES | PAGE

FINAL TECHNICAL REPORT

I. INTRODUCTION

In the coming century ground combat commanders will face considerable challenge from a changing and diverse military environment. These changes encompass all aspects of the battlefield: the operating environments will vary greatly; the nature of the threat will range from sophisticated to primitive; the types of operations will span typical mid-intensity combat, nation building and counter drug activities; the presence of advanced sensor and communication technology will provide more data than can be easily assimilated; and the training of commanders and staff personnel will pose significant new challenges. The Army is keenly aware of and preparing for a future that portends great change associated with land force dominance. In July, 1993, the Office of the Secretary of the Army published, The Army Enterprise Vision, a pamphlet describing the strategy intended to successfully prepare for future battlefields. It acknowledges these all-encompassing changes and emphasizes their importance. The expressed purpose of The Army Enterprise Vision is to "support US Army Warfighters into the 21st Century."

A hallmark of the future battlefield will certainly be advanced technologies. Inordinate amounts of information in real and near-real time will be the rule not the exception. The operational paradigm of the Cold War was based on detecting a target, deciding what to do about it, and then selecting a destroy option. The new operational paradigm will decide in advance what targets are key to the success of a friendly operation, detect and localize targets using an array of advanced sensors, then pass the information to a smart system that will destroy the target without further intervention. Recent combat experience in Operation Desert Storm provided a glimpse into an operating environment where seeing and attacking occurred nearly simultaneously for some types of targets. These nearly simultaneous aspects of future combat operations bring new challenges to commanders in the management of the battle environment.

General Frederick Franks, the Commanding General of the Army's Training and Doctrine Command (TRADOC) views the changes in the future battlefield to be of such magnitude that the traditional functional descriptors associated with Battlefield Operating Systems (BOS) are inadequate. New concepts, e.g., Battle Dynamics, are being developed to account for the evolution of full-dimensional operations for the strategic Army of the next century because the BOS concepts do not accommodate the complexity of the future environment. TRADOC's view of the dynamics of the new battlefield stresses the criticality of digitization of the battlefield and battle vision to successful future command operations. The new challenges for commanders are multi-dimensional. They are predicated on the need to integrate vast amounts of friendly and enemy information in short periods of time by covering large geographic areas quickly. The new Battle Dynamics, as they are called, include Battle Command, Battle Space, Depth and Simultaneous Attack and Early Entry. The terms themselves are intended to convey a departure from historically constraining operational categorizations.

Historically, battle commanders have enjoyed a pace of information flow and development that allowed processing and assimilation to be managed in chunks of hours. Even today Commanders use an information portrayal system based on paper maps generally scaled to the

distances their units are expected to travel or their weapons shoot. Overlays on the maps layered important current, as well as historical data, to create situation maps (SITMAP) or graphic images of the relevant current situation. Managing a SITMAP and what it conveyed required intensive attention by staff personnel. In the future, effective management of an increasingly complex battlefield will require the commander to instantly visualize and quickly grasp the implications of friendly and enemy situations, and battlefield terrain. The decisions that must be made, based on the visualization, in order to exercise command and control over allocated combat power will be made at an increasingly accelerated rate. These operational ingredients dictate that the commander of the future must have the ability to master the management of data collection and integration. The commander must then be able to incisively discern the meaning of the information. The standard military map may remain a future mainstay for unit navigation, but its role will diminish in the complex battle command management environment of the future as the capabilities of automated enhancements grow.

Because of the greater complexity and the diversity of future operational environments, emerging systems and doctrine will incorporate: 1) networks for widely distributing information, 2) descriptive models that bring reliable clarity rather than uncertain predictions to the command environment, 3) flexible sharing of information, based on broadcasting battlefield information to all echelons and 4) command display systems capable of sending and receiving images and graphics while on the move. Situational information, once presented a few times daily in the command briefing or the detailed analytical report requiring hours of reading will occur much more frequently and be largely visual. In the context of these four points, information becomes a dynamic weapon, a combat multiplier.

Battle Command

The Army is preparing for the future through a variety of initiatives that will serve to define new constructs and doctrine. New and future field manuals are likely to define the Army of the twenty-first century in these dramatically different terms. An emerging TRADOC construct of particular interest is Battle Command, because it refers to the art of command and encompasses new command support systems, new operating procedures, and new organizations.

Field Manual (FM) 100-5 links the assimilation of information, visualization of the battlefield, and assessment of the situation to battle command (p. 2-14). Battle command, the FM goes on to say, is more an art than a science, and is guided by intuition and feel gained from years of practice and experience (p. 2-15).

In a discussion of future battlefield dynamics and complexities, LTG Wilson A. Shoffner, Commander of Combined Arms Command (1993), states that "Command is primarily an art. Commanders formulate concepts, visualize a future state, assign missions, allocate resources for those missions, assess risk and make decisions." The concept of battle command as an art encompasses these responsibilities which Shoffner refers to as the commander's business. In order to perform these responsibilities, "the commander must be able to see and understand their present state, establish a vision of a future end state, and to articulate a unifying concept of operations" (Shoffner, 1993).

Digitization of the Battlefield

The battlefield will provide the commander with a tremendous amount of information that will require rapid assimilation for effective battle command. The Army will use new processing, communication, display and sensor technology to, in effect, "digitize" a view of the battlefield. The digitized version will be transmitted across the breadth of a command, creating a distributed view open to the inputs, validation or correction of numerous participants. The brigade commander will have information that includes precise grid locations of individual soldiers and vehicles, to video imagery of threat activity from organic and other sensors that in the past were reserved for use by echelons above Corps.

Advanced technology that permits digitization of the battlefield encompasses portable computers, high speed communications networks capable of transmitting digitized data, and specialized display devices for presenting combat-critical information. This technology contrasts dramatically with voice radio technology and manual processing of information, not long ago the standard among combat units.

The digitized battlefield provides powerful capabilities to acquire and disseminate large quantities of information. The speed and reliability with which this can be accomplished offer great potential in any operational environment. On balance, emerging technology can provide the information that enables the commander to "see the battlefield" more comprehensively and accurately, with updates occurring more quickly.

The Army is making great strides in integrating advanced technology in combat systems. The Maneuver Control System (MCS) is designed to provide combat maneuver elements with digital planning and control capabilities down to the battalion level (Anderson, 1990). The MCS supports exchange of information among armor, infantry, aviation, engineer, signal, chemical, and military police units. This system was used by some divisions during Desert Storm operations (Robinson, 1991). TACFIRE and AFATADS are well-known systems enabling fire support personnel to coordinate indirect fires by digitally exchanging reports, messages, and some graphics (Department of the Army, 1991). Tactical fire support elements across the battlefield are linked including forward observers, maneuver fire support teams, fire support officers, and indirect fire units.

Collection and transmission of large quantities of information for battle command requires secure, high-speed, high-capacity data distribution systems. Two such systems recently fielded by the Army are notable. The SINCGARS system handles data and voice transmissions by means of digital burst technology (Association of the U.S. Army, 1992). It is intended as the primary communications means within the brigade, with a C3 support role among combat support and combat service support units at the division and corps levels. The Mobile Subscriber Equipment (MSE) system is designed to provide secure voice, data, and facsimile communications at the division and corps levels (Association of the U.S. Army, 1992). This all-digital network supports mobile as well as stationary users. Both the SINCGARS and MSE systems were deployed in Desert Storm, where they played key roles in tactical C3 activities (Robinson, 1991).

Digitizing the battlefield is the process that will provide the information future commanders will use to rapidly visualize their entire operational environment.

Training Battle Command

To realize the potential of this technology, the battle commander and the staff must come to the battlefield equipped with the ability to use the tools to rapidly assimilate information, know how to visualize the current and future state of the battlefield, and then use the visualization to formulate plans and direct actions under conditions of time and physical stress. These factors prescribe the need for training new skills and developing expertise in commanders and staff personnel at all levels.

Expertise is generally considered to be gained only from experience. The widely diverse mission areas and conditions the Army must be prepared to encounter suggest there is no practical way to accumulate the requisite command experience. Research must identify methods to create experiences, develop backgrounds and train in preparation for the future. Klein and Hoffman (1993, in press) define the expert as someone "... with an enormous background of experience, who has an intuitive grasp of each situation and zeroes in on the accurate region of the problem without wasteful consideration of a large range of unfruitful, alternative diagnoses and solutions." Again with reference to LTG Shoffner's discussion, "... it is our commander's intuition that win America's battles." But what steps can the Army take to be less reliant on raw intuition and more proactive in creating the opportunities to develop expertise?

The training of expertise and the development of appropriate tools and methods for enhancing the soldiers ability to visualize the battlefield, is a mandate for the future. Training programs must respond to the needs of the commander. Before these training programs can be developed, expertise and visualizing the battlefield must be well understood. This report lays the groundwork for identifying human performance issues associated with the training of expertise and visualization of the battlefield.

Organization of the Report

This report documents the efforts of a front end analysis aimed at determining the scope and desirable approaches for meeting the requirements of future battlefields. The primary focus has been to capture and assess what is currently understood about emerging systems, the nature of expertise and the nuances of battlefield visualization. The report identifies what yet needs to be understood, and poses research questions that will lead to a thorough understanding of expertise and visualization and its role in the new battle dynamics. Finally, the report includes suggestions for research that will fill the gaps between current capabilities and future needs.

The next chapter presents a discussion of emerging technologies that support visualization of the battlefield, specifically communication and sensor systems, and identifies potential measurement constructs for assessing battlefield visualization and unit performance. The focus is on both the products and processes of battlefield visualization.

The third chapter discusses the nature of expertise and its application to the tactical domain via a literature review of scientific and military literature. Emerging from this review are implications for investigating battlefield visualization as an aspect of expertise.

A definition of visualization of the battlefield (VOB) that can serve as a foundation for subsequent research is next developed. The subsequent research will be designed to develop a more complete understanding of the phenomena and lead to the development and fielding of interventions that enhance the abilities of field commanders to visualize the battlefield.

Chapter five presents a review of Army training in battlefield visualization, focusing on the Tactical Commanders Development Course and Battle Command Training Program. The report concludes, in chapter six, with suggestions for further areas of research addressing visualization of the battlefield.

II. EMERGING VISUALIZATION TECHNOLOGY AND MEASUREMENT METHODS

The process of visualization, in part, depends on the sources and kinds of information that are available to the commander. Information capture and communication is an area that is currently subject to considerable technological changes. These changes will affect how visualization processes are conducted, what products will be developed by these processes, and how these products will be communicated to the commanders of subordinate units.

Evaluating the effect of emerging technologies on the processes and products of visualization will require techniques for measuring battlefield visualization and unit performance. These methods will help to determine how emerging technology will affect visualization, and how visualization, in turn, will affect battle outcomes.

This chapter describes emerging technologies related to battlefield visualization, specifically technologies for sensors, communication, and displays. It then presents a general discussion of problems of measurement, and a description of methods for measuring the products and processes of battlefield visualization.

Future Technology for Visualization

In order to determine the battlefield information available to support commanders' battlefield visualization needs, the following paragraphs present the results of a survey on emerging technologies. The survey focuses on communication, sensor, and display systems feeding brigade battle command functions through the 2010 time frame.

Communication Systems

The communication systems which are the cornerstone of the digitized battlefield are described in Table 1 (Appendix B provides a table of characteristics -- volume, periodicity, etc. -- for each of these systems). With the exception of B2C2, all systems will be fielded by 1997. B2C2 is expected to be fielded by 2010 and IVIS reporting capabilities are expected to expand during the same timeframe. Figure 1 presents an overview of the digitized battlefield by depicting the brigade communications and sensor systems through the year 2010.

The communications systems in Table 1 are of two general types: those that enable the rapid and secure transmission of battlefield information, ACUS-MSE, IDM, and SINCGARS; and those that provide the information for transmission, AFATDS, B2C2, IVIS, MCS, and the SRC. The information provided by the latter ranges from precise grid locations, via the Global Positioning System (GPS), for individual soldiers.

ACUS-MSE	**Army Common User-Mobile Subscriber Equipment** is a mobile radio telephone system based on digital technology that allows full use of redundant nodal switching in single channel access mode to subscribers from battalion to corps and linked to TRITAC systems at corps and above.
AFATDS	**Automated Field Artillery Target Delivery System** provides the capability to do fire planning, C^2 of FA units, ballistic fire direction and limited combat service support for FA units.
B2C2	**Battalion Brigade Command and Control** is a software development effort to link together separate C2 information systems at these two levels.
IDM	**Improved Data Modem** enables the transmission of targeting data to and from airborne observers, airborne weapon systems, and fire support systems on the ground. Provides links to AFATDS and IVIS.
IVIS	**Intervehicular Information System** is an automated C^3 device that supports the transmission of select combat reports and Global Positioning Data (GPS) through SINCGARS radio.
MCS	**Maneuver Control System** supports the exchange of blue battlefield information such as OPLAN/OPORD, C^2, and combat service support.
SINCGARS	**Single Channel Ground to Air Radio System** is a family of lightweight combat radios for infantry fighting vehicles and aircraft that uses a frequency hop system, allows digital bursting of messages, with a high level of communications security. Will replace current family of Army radios from man-portables through vehicle mounted AN/VRC systems.
SRC	**Soldier Radio Computer** will be carried by the individual soldier and contains sensors that enable the automation of selected tactical information. It provides GPS data and allows the transmission of formatted battlefield reports, as well as video recording and transmission capabilities.

Table 1. Communications systems available through 2010.

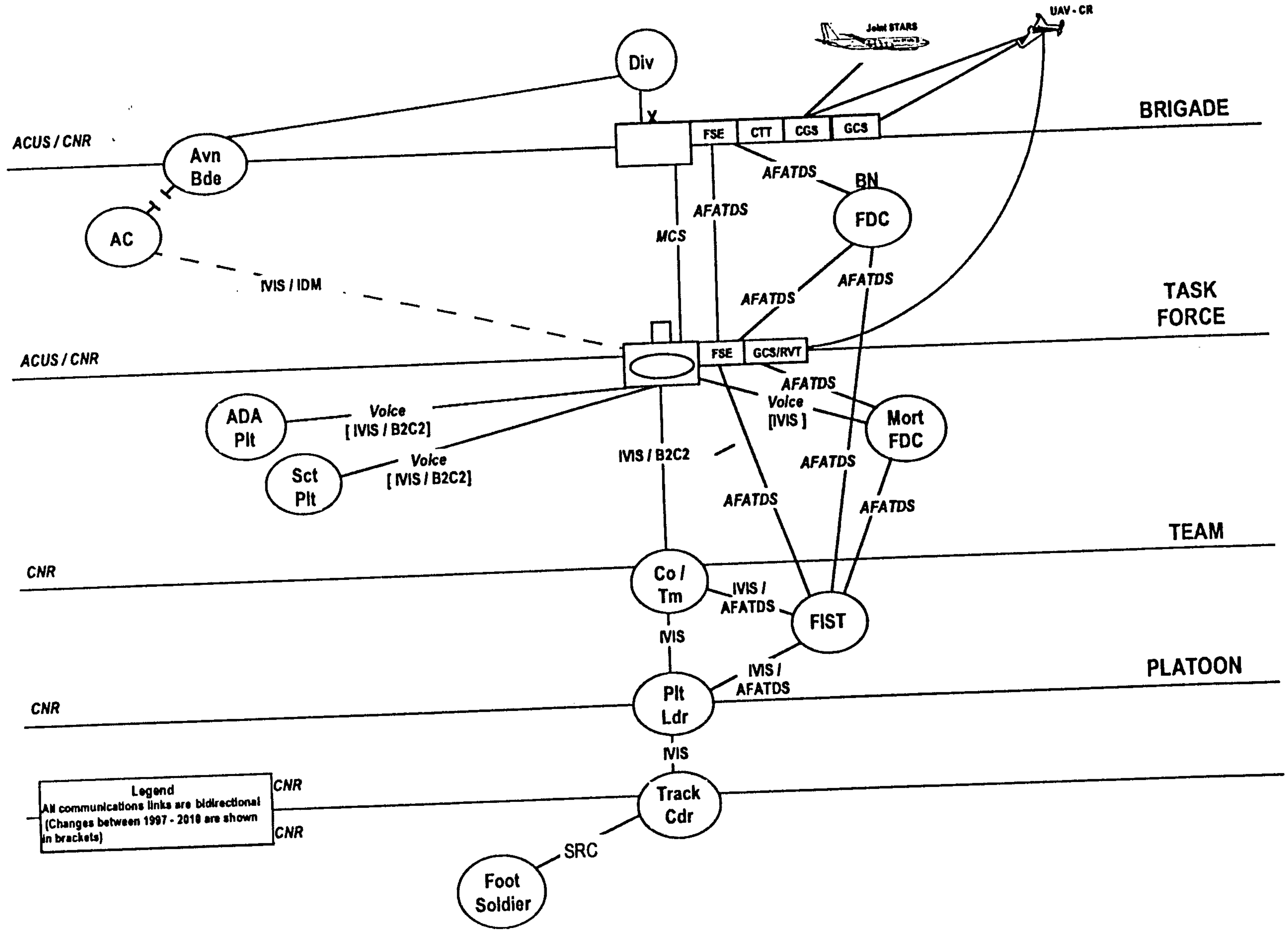


Figure 1. Brigade communication and sensor systems (1997 through 2010).

and tanks to formatted combat and status reports and targeting locations; increasing knowledge of friendly and enemy force locations and enabling the massing of direct and indirect fires.

A prototypical automated C3 system is represented by IVIS, which will be fielded on the MIA2. The Army currently has 19 prototype MIA2s and is procuring 62 more. However, in 1994 about 1,000 M-1s will be upgraded to the A2 configuration with IVIS (Goodman, 1993). IVIS is comprised of three primary components, POSNAV, a grid-map, and a reporting capability. POSNAV, using GPS, allows the precise grid locations of so-equipped vehicles to be displayed on a monochrome grid-map display. POSNAV also supports navigation and the establishment of digitized waypoints and routes to which the driver navigates.

The reporting capability of IVIS includes the capability to send and receive select formatted combat reports. By lasing to friendly or enemy vehicles, precise grid locations can be forwarded with these reports (future plans call for IVIS to be tied into AFATDS, supplying precise target locations). Rudimentary overlays can also be received and displayed on the grid map. IVIS will provide the commander, whether receiving information at a stationary command post or in his tank fighting the battle, with real time information on the status of his own forces; and information on enemy troops via formatted combat reports.

Sensor Systems

Because of current brigade headquarters organization, there are currently no sensor systems organic to the maneuver brigade commander; information flows to the brigade commander over combat net radio. However, future brigades will have access to sensors providing high volumes of real and near-real time information regarding the enemy situation and battle execution. Table 2 describes the brigade systems through which these sensors will be accessed (Appendix B provides a table of characteristics -- volume, periodicity, etc.-- for each of these systems).

According to the US Army Intelligence Center's IEW Processing Architecture (1993), the information provided by these sensors will be made available to the commander via the Brigade Analysis and Control Element (ACE). At the Brigade ACE information from these sensors feed the All Source Analysis System (ASAS) to support ACE functionality (collection management, dissemination, all source production, targeting, data base management, and HUMINT). Thus, ASAS becomes the integrator of the common enemy picture and the source of information for battlefield visualization.

The communication and sensor systems described in this section provide independent means for deriving friendly and enemy battlefield information. The imperative will be to provide the means to effectively integrate this information into a coherent whole.

CTT	The **Commander's Tactical Terminal** receives GRCS/U2, TIBS, TRAP/TADIX-B data and produces COMINT and ELINT reports.
GSM	The **Ground Station Module** receives data from JSTARS, OV-1D, UAV, JSTARS, and CTT; produces reports and JSTARS/UAV imagery to ACE.
GCS/RVT	The UAV **Ground Control Station** and **Remote Video Terminal** controls sensor flight and receives imagery; produces reports and screen capture of the UAV video.
CGS	The **Common Ground Station** receives data from JSTARS, OV-1D, UAV, JSTARS, and CTT. Correlates IMINT and SIGINT.

Table 2. Brigade systems supplying sensor data

Battlefield Displays

Our review of on-going research and government-fostered manufacturing initiatives concerning high definition displays indicates that their availability will rapidly influence projected systems. This section addresses strides in display technology likely to be realized within the next ten years.

Advances in display technologies. The expansion of available display technologies has been fueled by several ARPA-funded high definition display research programs. The display technologies under research range from 1-square inch to 450-square inches diagonal and can be used in head's up displays (HUD), the cockpit, or large displays for real-time intelligence image analysis and processing. A further research initiative is aimed at the development a display driver chip that lessens bulk (slicing depth), reduces power consumption, and increases the number of gray levels (resulting in more colors).

There are two categories of displays which have potential application to the commander's visualization of the battlefield: traditional and virtual displays. Traditional displays will be available to the commander while at the Main CP or other relatively fixed site(s) with ample power supply. Reduced, or miniaturized traditional displays will be available to the commander while on-the-move or in more confined spaces with less power supply. Displays available on-the-move are likely to provide a subset of the information provided by their larger counterparts. Virtual displays, whether on-the-move or in fixed locations are likely to provide information distinctly different from traditional displays.

Traditional displays. Currently, displays are either electro-mechanical CRTs or flat panel. Active matrix liquid crystal displays (AMLCDs)--a high definition display technology--are

expected to replace CRTs in most weapons systems over the next ten years (Galatowitsch, 1993), particularly where active motion displays are required. While the cost of AMLCDs is higher than CRTs, so is their technical performance.

Current military AMLCD applications include the F-22, the RAH-66, the space shuttle, and a 6 X 6 inch retrofit display for the C-141. While current applications focus on avionics, as C^3 and analysis systems rely more on full color active displays, are likely to benefit from the technology.

Virtual displays. Virtual displays include HUDs and head mounted displays (HMDs). HUDs are generally of projected onto a windshield or cockpit glass and provide system operation information. HMDs generally project augmented reality (virtual objects interacting with the real world) directly onto the retina or onto miniature vector CRT goggles.

Current developmental projects employing HUDs are focused at the operator level, be it tank gunner or helicopter pilot with little applicability to command and control. Augmented reality research and development, while accelerating rapidly, remains a thing of the future. Systems utilizing this technology are unlikely to be fielded within the time frame under consideration.

There are three aspects of display technology that bear on the ability to support the brigade commander's battlefield visualization: size, definition (resolution and color), and display type (HUD, HMD, traditional screens). Display size, in part, defines the amount of information that can be successfully displayed to the brigade commander. Larger screens can provide more information in a greater variety of scales and formats, with greater detail. However, the dimensions and power requirements of larger screens limit their use to relatively stable locations.

Smaller displays (with lesser power requirements) can support battlefield visualization while on the move in a variety of vehicles (tracked, wheeled, or aircraft). The reduced size, obviously, means that less information can be successfully displayed. Therefore, displays supporting on-the-move systems can provide only a subset of the functionality resident in their more fixed counterparts.

The ability to provide high definition displays with greater resolution and contrast and far more colors will enhance visual richness. This richness provides an abundant palette with which to develop interventions for the support/enhancement of VOB. High definition also mitigates psychophysical problems associated with current display technology, broadening the environmental applicability.

For the time period under consideration, the brigade commander is likely to have available only the traditional-type display screens (albeit, with greater variation in size). HUDs are not being applied to the command and control problem and HMDs are still in the R&D stages. However, with the greater range of display size and high definition, the traditional-type display screen should provide a wide playing field for the development of VOB interventions.

Given the rapid pace of research, development, and manufacturing initiatives, display technology within the next 10 to 15 years are likely to provide the brigade commander with acceptable rugged, high definition color displays deployable in the CP, the mobile TOC, or most varieties of vehicles. Systems supporting battlefield visualization, or interventions are unlikely to be hindered by a lack of quality displays.

Implications of Emerging Technology on Measurement

The emerging technologies for sensors, communications, and displays will provide commanders at all levels with more information that is both more accurate and more timely. One could easily imagine that the information available to commanders in future battles will allow them to plan and execute maneuvers that synchronize combat power on transitory enemy weaknesses. After the battle, the commander could review performance with his unit, and use this information to plan future operations. On the other hand, it is also possible to imagine a future in which there is such a wealth of information that commanders are drowning in a sea of data.

Which of these alternative futures occurs depends, in part, on two issues. The first is related to the nature of expertise. As the discussion on the nature of expertise will reveal, experts will be better able to sort through and make sense of this sea of data. Secondly, what information is collected and how it is presented to the commander and his staff can mitigate the effects of the profusion of information. Focusing on the latter, we begin this section by discussing issues related to commander workload. We then turn to issues related to measuring and evaluating unit performance. Finally, we consider the process of making predictions about the future, whether these predictions are made by the commander or by a type of combat model.

Commander Process and Workload

For certain types of information, the amount of information that must be understood and processed does not necessarily increase cognitive workload. For example, it does not require more workload to perceive a color photograph of a scene than it requires to perceive a line drawing of the same scene. In fact, it may require additional workload to "fill in the details" that are missing from the line drawing. Furthermore, simple representations of objects with low information content are often subject to multiple interpretations and illusions. Effects similar to perceptual illusions can occur when we are predicting future events. When the best information we have about an event is statistical, our assessment of the likelihood of that event can also be subject to multiple interpretations and illusions.

Experts can process large amounts of information by chunking it into complex patterns. Since nearly everyone is an expert at visual perception, we perceive the complex scene instantly with minimal workload. Specialized experts, such as expert commanders, visualize the complex patterns that are specifically relevant to their duties, based on insight into force capabilities. The ability of the commanders to detect relevant patterns can be influenced greatly by the content or

the format of the information that is the input to the command estimate process. It is relatively easy to imagine methods for presenting information that would greatly increase commander and staff workload. For example, a common method for processing sensor information in the past was to obtain information from verbal or written reports and subsequently to post this information on a map of the battle area. Clearly this process presents a bottleneck to effective use of the information and makes it impossible to increase the amount of information available without greatly increasing commander and staff workload. Consequently, the effects of the new sensors on commander process need to be considered in combination with the emerging communications methods and displays.

It may be useful to consider each piece of incoming information as having a "processing overhead," as well as a value to the commander. The format of the information can increase or decrease the processing overhead, while the content of the information determines its value. The expertise of the commander and the methods used by the commander and staff to process incoming information mediate the effects of information format and content.

The ability of the commander to visualize the battlefield will also be affected by variations in the quality or timeliness of information. For example, if the position and status of friendly forces are current, but battle damage assessment has not been completed for enemy troops, the information presented to the commander will be of variable timeliness. The commander will need to adjust his perception of the situation, based on the uncertainty of enemy troop strength. This adjustment will probably be very difficult for the commander to make, and there may be a temptation for the commander to assume that because most of the information is accurate and timely, that all of it is. The effect of variable quality on commander's visualizations is a topic that requires additional research.

Commanders are trained to use specific methods to develop and convey their intent and to guide the mission planning process. Research (e.g., Lussier, 1992) indicates that they do not always use this process. From a measurement perspective, our primary interest here is in what information is used, how it is gathered, and how broad and deep courses of action are analyzed to develop a visualization.

Cognitive psychologists have developed many methods for investigating planning processes. Studies in which planners think aloud while solving a problem can provide much useful information about the planning process. Often these methods are too obtrusive, and it is necessary to rely on interviews with planners after the fact. Although there are some problems with this method, usually it is possible to get useful and accurate information from such interviews. A final general method for measurement is process tracing. In this method, the planner is required to explicitly request all information that he or she requires to complete the plan. The types of information requested and the order in which it is requested are used as the basis of inferences about the planning process.

To determine the quality of a commander's vision, we must know how well the commander understands the current state of the battle, how well he can predict the outcomes of alternative courses of action, and how well he can evaluate the impact of these outcomes on the

mission. We would expect outcome predictions to be less precise for predicted events that are far in the future relative to events that are closer in time. A major questions regarding the evaluation of the visualization process is how quickly do predictions degrade, and what situations lead to more rapid degradation.

Evaluation of the visualization must take into account the dynamic nature of the battle. Most existing research has taken a snapshot of the battle at a single time, and used this picture to make predictions of the outcome of the battle. A complementary method that has considerable potential looks at both near- and far-term predictions and attempts to identify when and how predictions can go wrong. Existing battle simulations, such as JANUS, as well as analytic methods for prediction, such as neural networks and regression analysis, all have potential utility for this research.

Unit Performance Measurement and Evaluation

The emerging sensor, communication, and display technology will allow much more detailed measurement of performance. These measurements will be directly useful in some areas, as described below. However, we will still need to develop constructs to use to aggregate performance information, to evaluate performance, and to determine training needs.

Currently, exercises conducted at the Combat Training Centers (CTCs) provide considerably more data than actual battles, including position, movement, firing and kill data. Information about exercises conducted using distributed interactive simulation (DIS) is recorded in even greater detail, including the position of gun tubes on individual weapon systems. Future systems will be able to provide some of the information that is currently available only at the CTCs or in simulation. We might use the information that is currently available at a CTC or simulation as a model of the information that will be available in the future for actual battles.

One of the important uses of performance data at the CTCs is in forming the basis for after action reviews (AARs). To have such a capability for actual battles would be a great help for planning follow-on missions, understanding enemy strengths and weaknesses, and providing feedback to the unit on its performance. With communications systems like IVIS and the SRC the capture of battlefield information for later playback and analysis should pose little problem.

Evaluating unit performance and measuring visualization have been closely linked in existing research (e.g., Goehring & Sulzen, 1993). Difficulties of evaluating unit performance have been summarized by Mirabella (1993). These problems are clarified when the unit is considered as a complex system, as has been done by McFann, Hiller, and McCluskey (1990), who stated that:

> Army Task Forces are open ended non-linear systems composed of subsystems which interact one with the other and with their environment. Task Forces as complex systems are unanalyzable into irreducible parts because the parts as with any open system are constantly being folded into each other by interactions and

feedback. ... The whole system is viewed as an interrelated process system and not necessarily hierarchical. (p. 2)

As described by Olmstead (1992), a system includes a set of parts that interact with the environment to perform a mission. Critical to the concept, according to Olmstead is "a degree of 'wholeness' which makes the whole something different from, and more than, the several parts considered individually and summatively."

The difficulty in evaluating performance, then, comes from the complex relationships among mission goals and the BOS. These interactions make it difficult to assess the overall outcome of a battle from more elementary information, such as the degree of terrain controlled or casualty ratios.

The rule that is used to aggregate all of these elementary values is complex, in part, because of the organization of mission objectives and BOS. For example, in a particular mission, a task force may be required to maneuver to the primary objective, satisfying secondary objectives on the way. When they reach the objective, they will have to defeat enemy forces and prepare for follow-on missions. The overall performance of the task force will depend upon how well they perform on each objective. However, different objectives have a different impact on overall performance. Failure to maneuver to the primary objective makes it impossible to defeat the forces there or to be prepared for follow-on missions. On the other hand, failure to take one of the secondary objectives may have little impact on the overall mission success.

It is important to note that the differences among the objectives is not merely a difference in importance. If it were, we could define a measure of performance that was a weighted sum of performance on each objective, with the weights representing the relative importance of the objectives. However, the relationship among objectives is more complex than that. Some objectives are primary; others enable the performance of the primary objectives; while yet others may support other units, possibly at higher or lower echelons.

Information for Analysis and Modeling

The emerging technologies can provide a wealth of information for analysis and modeling. This information can be used to develop and evaluate doctrine and to provide feedback during and after missions. Ultimately, the analyses supported by this information could provide some kind of automated guidance to the commander in developing his intent and providing planning guidance to his staff. However, there appear to be real limits to reliably predicting the outcomes of battles.

Because of the complexity of the battlefield, small events can have a large impact on the outcome. This fact is illustrated by an analysis of the performance of the Patriot missile system during the Persian Gulf war (GAO, 1992). The specific event being analyzed was an attack by a SCUD missile on Dhahran, Saudi Arabia. The Patriot system did not engage this missile. In their analysis, the GAO determined that the failure of the Patriot system in this case was due to an accumulation of rounding errors in the timing system of the Patriot. This error caused an error

in time of about 10^{-7} seconds for each 1/10 second. Accumulation of these errors caused a mismatch between the computed time and the radar, which led the system to fail to identify the incoming SCUD. In this case, because of the overwhelming superiority of the Allied forces, the outcome of the war was not affected. However, it does illustrate that seemingly inconsequential errors can have a substantial impact on the course events in a complex system. Likewise, the commander's visualization of the battlefield is guaranteed to have some errors, and the feedback provided by emerging technologies will be important in adjusting plans as these errors are uncovered.

The complexities of battle will make it difficult to predict its outcome using any kind of simulation, whether it is the mental simulation of a commander or the mathematical simulation of a computer. As Jenson (1987) stated generally about nonlinear dynamic systems,

> There is no faster way of finding out how a chaotic system will evolve than to watch its evolution. The system itself is its own fastest computer (p. 179).

The impact of small changes in the initial conditions on the outcome of actual battles has been investigated by Singleton (1992, cited by Palmore, 1992), who examined data from over 100 battles fought in the last 50 years. The results of his analysis indicated a significant unpredictability of battle outcomes. In fact, historical battles showed considerably more variability in outcome than simulated battles (Palmore, 1992).

Analyses of combat performance data have often focused on the final outcome of the battle or exercise, rather than the entire sequence of events that make up the battle. For example, Rakoff, Laskey, Marvin, and Mandel (1991) made two attempts to predict unit performance using a neural network model. The first attempt looked at notional performance data, and attempted to predict subjective judgements of overall success. In a second research activity, Rakoff et al. (1991) developed a neural network model to predict the final outcome of a combat board game from fourteen measures of effectiveness taken in the first engagement of the game. The models they developed made accurate predictions in the first attempt, but not in the second.

The research of Dryer (1989) and of Goehring and Sulzen (1993) limited the weapon systems considered to tanks and systems that could destroy tanks. By considering only these systems, they were able to develop relatively simple measures of ground maneuver concentration of forces (or "mass") that was closely related to measures of overall performance. Thus, they were able to predict performance relatively well from measures made early in an engagement.

In summary, there are limits to our ability to conduct analyses that would help the commander develop and specify his intent. However, research in this area has focused on predicting the final outcome, rather than the entire sequence of events that make up the battle.

Research Needs

Future technology will provide both the commander and the combat analyst with a wealth of data describing the flow of combat. A key concept in determining future research needs is the view that researchers should be concerned with the entire course of the battle, not just the final outcome. We address three areas in which there are research needs: information management strategies, measurement of visualization, and information analysis strategies.

Information Management Strategies

The effectiveness of sensor, communication, and display technology to improve mission planning effectiveness depends on how the information they provide is managed. Particular concerns for future research are the commander's cognitive workload and the effects of missing, misleading, inaccurate, or out-of-date information. We also need to be concerned with how information management strategies interact with different levels of commander expertise. The results of this research should provide guidelines for the design of methods to process and present the information that will be gathered by future sensors and communications systems.

Measurement of Visualization

Visualization is a concept in need of an operational definition and specific measurement procedures. In a later section, we argue that visualization is a process of mental simulation. If this is so, then we may use concepts of simulation to measure the outcomes of the visualization process. The event list is central to representing simulation models, specifically discrete event simulations. We think that a measurement construct based on comparing the event list, as envisioned by the commander, to the actual event list holds considerable promise as an assessment of visualization of the battlefield. However, because of its inherent multidimensional nature, measurement based on comparing event lists will present analytical difficulties.

In addition, the measurement of visualization can take advantage of similar research that has been conducted regarding the related concept, situation awareness. For example, Endsley (1990) has developed methods for assessing situation awareness of pilots performing simulated missions. Lickteig (1991) has applied similar methods to address platoon-level command and control skills. We think that these concepts will provide a useful starting point for developing measures of visualization.

Information analysis strategies

Existing research has attempted to predict the final outcome of a real or simulated battle from measures made early in the engagement. There are many sources of error variance that can make predictions of this type highly inaccurate. We think that a much more useful strategy for information analysis would be to make predictions of more proximal events. That is, the initial

conditions could be used to predict early battle outcomes. The actual success or failures of the early parts of the battle could then be used to predict somewhat later outcomes, and so forth until the battle was completed. Such an analysis could produce a prediction technology that could use the wealth of information to correct errors and adjust predictions accordingly. Near-term predictions would remain fairly accurate, but accuracy would drop off for events far in the future. This type of prediction is somewhat analogous to weather prediction: short-term forecasts are considerably more accurate than long-term forecasts, and the short-term forecasts can be updated continuously as conditions change.

III. THE NATURE OF EXPERTISE

The preceding chapter describes a complex, dynamic battlefield of the future. To ensure success on this battlefield, commanders will have access to an enormous amount and variety of information. Furthermore, an array of advanced technology devices will be used to detect various environmental factors and to help the commanders analyze the resulting mountain of information. Despite the emergence of advanced technology designed to support commanders on the battlefield, the commanders' intuitive understanding of battle and their ability to visualize the battlefield will distinguish between winning and losing. Success on these battlefields will require that commanders be true experts at the art of war.

What are experts? What distinguishes them from journeymen or novices? How can we transition journeymen to expert commanders? All of these questions are of interest for this project. We must start by understanding what we currently know about expertise. It is important to note that we are interested primarily in the transition from competent performers non-experts -- or journeyman -- to experts.

This chapter presents the findings of a review of the research literature that addresses issues concerning expertise. This review is not intended to be exhaustive. Rather it is a broad-brush review of the highlights of the existing literature. The objective of the review is to develop some notions of the nature of expertise and how it may be manifested in Army field commanders. Thus, this review included military training and doctrinal literature as well as the scientific literature.

This chapter comprises four sections. The first describes the characteristics of experts. The second describes a perspective for studying expertise and one model of how experts make decisions and solve problems. The final section describes several skills of experts and how they may apply to field commanders.

Nature of Expertise

We generally know who the experts are. They notice the subtle but critical cues that others miss. They can reliably make discriminations that are opaque to others. They have clear judgments of the appropriate ways to act in a situation. They can anticipate what is supposed to happen next, and their expectancies are so clear that they quickly notice when they are wrong; they can rethink their interpretation of what is going on (Klein & Hoffman, in press).

Novices see only what is there; experts can see what is not there. With experience, a person gains the ability to visualize how a situation developed and to imagine how it is going to turn out.

Novices see only what is there. As long as people have a general sense of what is going on, they are alert to what is happening in front of them. Chi, Feltovich, and Glaser (1981) found that both expert and novice physics students could identify the critical cues in a physics problem;

the advantage that experts had was in perceiving the interactions among the cues. Brezovic, Klein, and Thordsen (1987) studied the decision making of tank platoon leaders and found that during field exercises novices who had just been introduced into the tanks could list as many different cues as the tank instructors. The novices were not overwhelmed with information, and they were reasonably aware of important items of information. Cue acquisition did not appear to be a critical component of expertise. Elstein, Shulman, and Sprafka (1978) found that accuracy of medical diagnoses was minimally related to thoroughness of cue acquisition. For most tasks, higher levels of performance do not necessarily depend on more powerful strategies for acquiring information that is directly perceivable.

Experts can see what is not there. Their experience lets them notice when something is missing. Consider the following example. A new employee in an organization made the observation that projects were usually left for the last minute. She drew this conclusion from watching how several technical reports were completed with considerable strain just before their deadlines. When she shared her observation, however, it was hotly disputed. In fact, the organization had just completed 10 proposals within the past 6 weeks with such little effort that she had not even known about them. In previous years, proposal writing had been a major burden and so extra care had been taken to prepare in advance. People who had been in the organization for several years could see the difference. The new employee had no way to detect the absence of frantic activities. She could notice the times when the system broke down, but not the times when it worked.

What nonobservable events can an expert detect? Only with experience can you visualize how a course of events is likely to unfold, so that you can see the expected outcomes even in the beginning. Only with experience can you form expectancies. Only with experience can you notice when the expectancies are violated, when something that was supposed to happen did not. And, only with experience can you acquire the perceptual skills to make fine discriminations.

What is expertise? How do people develop it? From his research, Shanteau (1987) identified fourteen psychological characteristics of experts (see Table 3). This list is probably not complete nor do all experts possess all of these characteristics. However, these characteristics provide some insight into the kinds of skills that we expect experts to possess.

Many of these characteristics are shared by many experts. However, not all kinds of experts share the same characteristics. Shanteau (1987) identified three dimensions that can be used to distinguish types of experts: perceptual-cognitive, substantive-assessment, and active-passive.

1. Experts have highly developed perceptual/attentional abilities. They are able to extract information that novices either overlook or are unable to see.

2. Experts have a better sense of what is relevant and irrelevant when making decisions.

3. Experts have an ability to simplify complexities. They can make sense out of chaos.

4. Experts have strong communication skills and can convince others of their expertise.

5. Experts know when to make exceptions. They know when and when not to follow decision rules.

6. Experts have a strong sense of responsibility.

7. Experts select which problems to solve. They know which decisions to make and which not to make.

8. Experts have overt confidence in their decisions. They believe in themselves and their abilities.

9. Experts have an ability to adapt to changing task conditions. They avoid rigidity in decision strategies.

10. Experts have a highly developed content knowledge base.

11. Experts have a greater automaticity of cognitive processes.

12. Experts have an ability to tolerate stress.

13. Experts have an ability to be creative. They are able to find novel solutions to problems.

14. Experts often have an inability to articulate their decision processes.

Table 3. Psychological characteristics of experts (Shanteau, 1987).

Perceptual experts rely on sensory skills. They are experts because they can perceive differences that are not apparent to others. Cognitive experts rely on their superior ability to think through problems. They are experts because they can discover relations not found by others.

Shanteau's (1987) second distinction is between substantive and assessment experts. Substantive experts must be able to draw on a considerable body of knowledge and use that knowledge to make their judgments. Assessment experts must be able to draw inferences and make predictions based on limited information. They are experts because they can make reasonable assessments in the face of considerable uncertainty. "Thus, some experts are valued because of their ability to make decisions based on large amounts of information, while others are experts because they can make good decisions with incomplete information" (Shanteau, 1987, p. 299).

Shanteau's third distinction is between passive and active experts. Passive experts make skilled judgments, but are not asked to act on these judgments. In contrast, active experts are skilled in acting on their decisions. Passive experts are relied on to provide information to others, whereas active experts are skilled in carrying out decisions.

Glaser (1976) suggested that the following changes occur when people develop expertise:

- Variable, awkward performance becomes consistent, accurate, complete, and relatively fast.
- Individual acts and judgments are integrated into overall strategies.
- Perceptual learning occurs so that a focus on isolated variables shifts to perception of complex patterns.
- There is increased self-reliance and ability to form new strategies when required.

How do these changes occur and how do experts reach a level of performance that extends beyond that of simple proficiency? Numerous authors have addressed these questions. The following paragraphs discuss briefly three of the prominent approaches: expertise as the development of higher-order strategies, expertise as a function of knowledge base, and expertise as perceptual/cognitive differences.

Some researchers have attempted to show that process differences exist between experts and novices. They believe that some people become experts because they develop and use different processes or strategies in solving problems. That is, experts use more advanced, effective strategies than novices. Much of this work has been done with children to explain why they are not as competent as adults (e.g., Flavell, 1971; Kail & Hagen, 1977; Ornstein, 1978). However, other authors have concluded that strategy differences are not the source of

performance differences (e.g., Chi, Feltovich, & Glaser, 1981; Hoffman, Burton, Shanteau, & Shadbolt, 1991).

A second approach to studying the origin of expertise investigates differences in the knowledge bases of experts and novices. Researchers (e.g., Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980) argue that expertise is a function of knowledge base. Experts develop richer knowledge bases, represent problems in more powerful ways, and take more advantage of stronger reasoning processes. Experts certainly possess deeper, richer knowledge bases than novices. However, it is not clear whether this difference is a factor of expertise or the essence of expertise.

Chi (1991) attributes expert performance to two characteristics: knowledge structures and strategies for problem solving and reasoning. Experts excel in their domains not only because they possess more knowledge, but also because they organize that knowledge differently from less proficient performers.

Chi (1991) characterizes this organization by schemas for declarative knowledge, production rules for procedural knowledge, and mental models that synthesize both. Schemas and production rules allow experts to represent problems in a deep way that provides access to automatic processes, to recognize patterns and chunks. Mental models are analogues of the real-world. They represent the objects and properties of a system. More important, mental models represent the structural, functional, and causal relations among the components. Finally, a mental model can capture the dynamic nature of a system in that an expert can mentally step through the model to see how a system or situation will play out across time.

Chi (1991) also notes that experts excel in their use of general strategies for problem solving and reasoning. Researchers have identified two particular strategies: analogical comparison or reasoning (Chi, Bassok, Lewis, Reimann, & Glaser, 1989) and divide and conquer strategies. Experts use analogical reasoning to compare a present case to previous, similar cases. Jeffries, Turner, Polson, and Atwood (1981) reported a decomposition strategy where experts break down a problem into its subparts, solve each subproblem, and then put all of the subproblems back together. Various studies have demonstrated that implementing these strategies does not constitute expert performance; these strategies are available to the novice as well as the expert. The difference in performance is related to how the expert applies these strategies and to the exceptional knowledge base to which they are applied. For example, both novices and experts search for analogies to apply. However, experts know how to pick the right analogy. They are able to pick one that shows understanding of both the analogy and the target problem.

Klein and his colleagues (Klein, 1990a; Klein & Hoffman, 1993) argue that experts develop advanced perceptual abilities that distinguish them from novices. Klein defines three aspects of expert perception: the ability to see typicality, the ability to see distinctions, and the ability to see antecedents and consequences. Each of these aspects is described below.

The ability to see typicality. Through experience and exposure to many situations experts develop an understanding of what is typical. As their knowledge bases develop, people may be able to recognize situations as familiar because they resemble previous experiences. However, Klein proposes that when people gain a great deal of direct experience, individual incidents become less vivid and blend together in memory. At present there is not satisfactory explanation of how experts can judge typicality.

A measure of typicality allows experts to rapidly size up situations. There is no way for a novice to judge what is normal and what is an exception. The ability to judge typicality enables experts to perform more effectively and efficiently. By quickly seeing which goals are feasible, experts can direct their actions and not waste any effort. By recognizing which cues are relevant, experts can avoid information overload. By anticipating what events to expect, experts can rapidly notice if they have misperceived the situation. By recognizing a typical course of action, experts can respond rapidly. This type of recognitional decision making enables experts to handle complex cases under time- compressed conditions where analytical methods would not be possible.

The ability to see distinctions. A second aspect of perceptual expertise is the ability to see distinctions. Experts are particularly better than novices in making fine perceptual discriminations. The effects of perceptual learning can be seen in common experience. Shanteau (1985) has demonstrated perceptual skill differences between experts and novices in a wide variety of fields.

The ability to see antecedents and consequences. The third aspect of perceptual expertise enables experts to visualize how a situation developed into its current state and how it will continue to develop. That is, experts are able to mentally simulate preceding events and subsequent events. Mental simulation is an important source of power. It allows experts to explain current conditions and to evaluate a course of action without comparing it to others.

Klein argues that the ability to perform mental simulations sets experts apart from novices and that experts are capable of handling a wider range of tasks nonanalytically than people with less experience. Klein's perceptual/cognitive view of expertise maintains that with experience, a person moves beyond explicit rules and strategies, rather than acquiring so many rules and strategies that they become automated or guided by higher-order rules.

Patel and Groen's (1991) research also points to the cognitive differences that characterize expertise. Their research focuses on medical diagnoses and the differences among experts, subexperts, and novices. They investigated the relationships among the accuracy of diagnosis, accuracy of critical cue recall, and directionality of reasoning (forward or backward). Previous research had shown that experts have superior memory skills in recognizing patterns in their domains of expertise and that they tend to work forward through a problem. Naturally, Patel and Groen found that experts diagnose more accurately than the other two groups. Surprisingly, they found that recall was not related to expertise. Thus, they reject the notion that expertise is the product of building a greater library of patterns to recognize. Patel and Groen's explanation is that experts use a macrostructure which filters out unnecessary information. Therefore, although

subexperts recall cues as well experts, they lack the macrostructure needed to identify the truly relevant cues.

Naturalistic Decision Making

Clearly, an abundance of literature exists describing what distinguishes an expert from a nonexpert and describing how experts acquired those characteristics. These studies have emerged from a variety of research paradigms and perspectives. Furthermore, an evaluation of this literature frequently depends on one's own personal perspective.

We believe that the most effective and productive way to study expertise is to investigate how experienced people perform in their natural work and living environments. Such a perspective enables researchers to study processes of people in real-world settings. This approach stands in direct contrast to the traditional decision research paradigms that study inexperienced decision makers performing well-defined, novel tasks in controlled laboratory settings. In recent years, a research field has emerged from a different perspective. Naturalistic Decision Making (NDM) is the study of how people make decisions in their workplace and in their personal lives. To learn how decision makers handle the complexities and confusion of operational environments, NDM researchers have moved their research away from the highly controlled and predictable laboratory settings and into the field to study domains that are complex and challenging. Several resources provide excellent reviews of NDM including Klein (1993) and Klein, Orasanu, Calderwood, and Zsambok (1993).

What makes natural environments particularly challenging for decision makers? Research has identified the essential characteristics of naturalistic decision environments (Klein, 1993; Orasanu & Connolly, 1993). Table 4 lists nine features that are particularly interesting. Not every domain includes these variables, and some naturalistic reasoning strategies apply even when most of these features are missing. Nevertheless, the features in Table 4 cover the most challenging aspects of operational settings.

Clearly, the characteristics described in Table 4 apply to the commander of a combat battalion or brigade as he plans for and executes a mission. The battlefield is a dynamic environment and the stakes are high. Information that the commander receives is ambiguous and often has gaps. Commanders work within teams that are distributed around the battlefield. Commanders have varying degrees of experience, but they are not novices.

Characteristic	Description
Time pressure	Decision makers have limited time in which to make decisions and implement responses.
Dynamic settings	Situations are not static; they evolve over time.
High risk	The consequences of errors are high for either the decision maker or others in the situation.
Shifting goals	Dynamic conditions change what is important. As situations evolve the decision maker must modify goals.
Feedback loops	Actions taken will alter the situation, and thus may dramatically affect the subsequent goals and actions.
Ambiguous, missing, and questionable data	Available data rarely paint a clear picture. Pieces of information may conflict with each other, be missing altogether, or be of unknown quality.
Cue learning	Experienced decision makers associate meaning with constellations of cues and with changes in cue clusters. These meanings are not available to novices.
Experienced decision	Most decision makers have some experience, ranging from journeyman to expert. Decision makers in real-world settings are rarely novices.
Teams	Decision makers often work together as teams.

Table 4. Characteristics of naturalistic domains

It is important to understand how commanders make decisions under these conditions, and to understand how their experience enhances their ability to make decisions and to solve problems. The field of NDM enables us to study these processes in the field as they occur. The following paragraphs describe some of the basic findings of NDM research. A description of a model of expert decision making follows this discussion.

NDM research has produced extensive evidence indicating that decision makers can use their experience to size up the situation, recognize it as typical in some ways, and identify the typical way of responding. Therefore, skilled decision makers may never have to consider more than one option when making decisions. The different strategies for contrasting options rarely

come into play. Of course, there are times when it is important to contrast optional courses of action, particularly for individuals who do not have sufficient experience. But for most cases, including very difficult incidents, the critical step for the experienced decision maker is to assess the situation. Once the decision maker understands the situation, an appropriate course of action is easily identified.

An incident reported by Kaempf et al. (1992) illustrates this point. The commander of an AEGIS cruiser needed to decide whether to shoot down a pair of F-4s that threatened the cruiser. On the surface, the decision was about two different courses of action: to engage or not to engage. On a deeper level, the decision was about assessing the situation by determining the intent of the fighter pilots.

On this particular day, the cruiser was escorting an unarmed ship through the Persian Gulf when two Iranian F-4s took off and began to circle near the end of a nearby runway. Each successive orbit brought the fighters closer to the two ships. The aircraft activated their search-and-fire control radars and acquired the ships. By the rules of engagement in effect, this was a hostile act. The AEGIS commander would have been justified in engaging the aircraft, but he chose not to. The AEGIS commander needed to defend his ship, but he decided that the two aircraft were not going to attack. How did he form this assessment?

The Captain tried to imagine that the F-4s were hostile. He could not imagine that a pilot preparing to attack would be so conspicuous. The pilots had been flying in plain view. They announced their presence by activating their radars. They even used their radars unnecessarily by keeping them on when travelling away from the ships. The Captain just could not imagine how pilots planning to attack would behave in this way.

In contrast, the Captain could imagine how the pilots were trying to harass him. All of their actions appeared consistent with this hypothesis. Therefore, the Captain inferred that the F-4 pilots were simply playing games. Once the Captain reached this decision about the situation, then determining a course of action was simple. He would take action to prepare his ship, but would not engage the aircraft.

This incident illustrates several insights derived from NDM research. First, people most often try to satisfice by finding the first workable solution rather than optimize by finding the best solution. Simon (1955) was the first to make this distinction. In operational settings, it is very difficult to determine what the best course of action is, even with hindsight. Decision strategies that try to calculate the optimal course of action only work when time is plentiful and the goals are clearly defined. For example, no one can say that the AEGIS commander was right or wrong in not firing at the F-4s as soon as they illuminated their fire control radar. In this case it worked out, because he avoided an incident by increasing his level of risk while retaining the ability to defend his ship.

Second, situation assessment decisions are distinguishable from course of action decisions. Sometimes, decision makers need to diagnose what is happening, and, perhaps, select one diagnosis from among several. At other times, the decision maker must determine which action

to take. In the F-4 example above, the commander was faced with a diagnosis decision. Several studies have shown that diagnostic decisions are predominant in natural settings (e.g., Kaempf et al., 1992).

Third, in operational settings, people use their experience to arrive at situation assessments. They can use context to help them draw inferences from the available cues. Fourth, in most cases, the situation assessment makes the appropriate course of action obvious. Many operational domains have extensive standard operating procedures and preplanned responses. Their purpose is to aid the decision maker by identifying the appropriate course of action. Planners spend considerable effort anticipating contingencies and identifying the responses for each. This removes from the decision maker the burden of generating courses of action, but increases the burden of correctly assessing the situation.

Finally, decision makers frequently must act with incomplete and often conflicting information. Decision makers often do not receive the information that would make a decision easy. This may be due to a variety of causes: poor communications, inadequate sensors, malfunctioning equipment, mistakes by others, or poor environmental conditions. These factors may also lead to conflicting information being received from different sources. Experienced decision makers anticipate these problems and learn methods for handling situations in which they receive inadequate information.

These insights from NDM research portray decision makers as capable of using experience to handle difficult situations without having to evaluate different options. This stands in direct contrast to traditional decision training that teaches students to generate many different options, carefully list the strengths and weaknesses of each, and calculate the best. Anything less is seen as deficient. According to the NDM framework, this advice may be useful for novices, but is incompatible with the way that proficient operators make decisions. The available data (Isenberg, 1984; Klein, 1989; Soelberg, 1967) clearly show that decision makers are quite successful, yet they do not follow the classical advice. Furthermore, departing from the classical advice is what experts are able to do to succeed. Thus, it is a model to emulate, not correct. Clearly, there are times to compare options, particularly for the less experienced. But, in highly procedural jobs, these times are relatively rare.

A discussion of one model of how experienced people make decisions in their natural settings follows. This is the Recognition Primed Decision (RPD) model of decision making. It is important to note that we use the term decision in a rather broad sense to include what has been traditionally known as problem solving. Therefore, we present first a brief discussion of our rationale for this choice.

Problem solving and decision making. Klein (in preparation, "A Recognitional Model of Problem Solving") has recently studied the relationship between problem solving and decision making; he reached a number of conclusions that are presented in this section. The two fields of problem solving and decision making have traditionally been studied separately. Problem solving has been the province of Artificial Intelligence and has concentrated on the way subjects arrange elements to solve puzzles (e.g., Greeno & Simon, 1988). Decision making research has

been the province of games theory and statistics, and has concentrated on the "moment of choice" in which subjects have to select one option from several alternatives (Keeney & Raiffa, 1976; von Winterfeldt & Edwards, 1986). The separation of problem solving and decision making has arisen because of historical reasons, and not for any theoretical grounds since the two fields are difficult to distinguish.

While we can distinguish problem solving (finding a set of actions to achieve a goal) and decision making (selecting one course of action from several alternatives) in theory, and we can point to paradigm cases of each (solving a puzzle, making a choice), the line becomes very blurred in naturalistic settings. Consider the case of an undergraduate student just finishing her first year of college. She may consider the possibility of transferring to another school that is closer to home, because she misses her friends. So, it appears as if she has a decision to make: stay at her original college or transfer to a second college. Nevertheless, in many cases the student will not proceed to make a choice, but will shift into a problem solving mode, checking on how many credits will be lost in the shift, gathering more information about the quality of the professors in her major field of study, reconsidering whether she should join a sorority, imagining how her grades might fall if she actually lived closer to home, checking on the availability of rides in order to make it easier to return, perhaps even planning to use her earnings for the summer to buy a car so she feels less trapped at the first university. These are all problem solving rather than decision making activities.

The artificial separation of problem solving and decision making can only be maintained if we restrict each field to a narrow focus that does not do justice to the phenomena of interest. In the field of problem solving, the emphasis on solving well-defined puzzles seems overly restrictive for reasons discussed in the preceding sections. In the field of decision making, the emphasis on choosing between options runs into comparable difficulty.

The literature shows some overlap between the terms "problem solving" and "decision making." Brim (1962) used the sequential model in Table 3 to illustrate problem solving, whereas Elbing uses it to describe a step-by-step decision making framework. We can see decision making restricted to the moment of choice, and therefore embedded in the problem solving process. Or we can treat decision making as broader than the final act of choice among alternatives, but encompassing problem solving activities as well. Some researchers, such as Berkeley and Humphreys (1982) argued that decision making is more than the moment of choice, whereas others, such as Gettys (1983) referred to pre-decisional processes to extend the province of decision making.

The selection of terminology seems to be one of convention. The basic research community would prefer to restrict the term "decision making" to the moment of choice, whereas the applied community is more likely to expand the definition of "decision making" to coincide with management, as Simon indicated.

The moment of choice is worth studying to help us in situations where the stakes are extremely high, the conditions are complex, time is available for analyses, and the decision makers do not have a large experience base. Issues such as where to locate a new airport,

whether to invest in a new technology, are reasonable opportunities to use methods such as Multi- Attribute Utility Analysis (von Winterfeldt & Edwards, 1986) and Decision Analysis (von Winterfeldt & Edwards, 1986). In such cases, we can bring the power of mathematical analyses to bear. Multi-Attribute Utility Analysis is simply a method for evaluating all courses of action in a standard set of dimensions, weighting the dimensions for importance, multiplying the ratings by the weights, and calculating the scores for each option. Decision Analysis uses judgments of subjective expected utility and probability of outcome, to calculate a preferred option.

Unfortunately, we have trouble generalizing these methods to time pressured settings and to experienced decision makers. Janis and Mann (1977) set a comprehensive procedure as the ideal for virtually all decision events, encouraging people to fully explore all reasonable options and all relevant evaluation dimensions. The advice offered by Janis and Mann ignores the range of studies showing the experienced decision makers do not compare options.

Minsky (1986) has described a paradox that arises from concentrating on the moment of choice. He called it Fredkin's Paradox, that the smaller the difference between two options, the more difficult the choice yet the less meaningful the choice. Fredkin's Paradox suggests that some difficult decisions may not deserve the attention we give them. Sometimes the pros and cons of the options are balanced so evenly that the choice doesn't matter. Even when the consequences may be great, the information we are using may be minor compared to the factors we cannot anticipate.

Another serious difficulty is that the moment of choice is relatively infrequent. Isenberg (1984) studied business executives and found that they rarely made classical decisions. Klein and Calderwood (1991) reported the same finding in reviewing studies of a range of specialists, including Army officers and firefighters. Kaempf et al. (1992) reported that 95% of the decision opportunities faced by naval officers in operational and training exercises were resolved without comparing alternative courses of action. Mosier (1990) has supported these findings in a study of airline pilots.

Therefore, decision making research has examined a limited, rare and relatively inconsequential phenomenon. Studying the moment of choice is too limited, as Berkeley and Humphreys (1982) argued, because there is much more to making decisions than deliberatively selecting between options. Gettys (1983) has described a range of important pre-decision processes such as problem detection and hypothesis generation. The moment of choice is rare as shown in the studies listed in the previous paragraph. The moment of choice is often inconsequential because of Fredkin's Paradox.

For these reasons, we use the broader definition of decision making in which it overlaps with problem solving. We believe that our research will be more productive if we cease to divide the phenomena of decision making and problem solving into separate paradigms.

The Recognition-Primed Decision Model

Several researchers have presented models of NDM. This section describes briefly one of these models, the Recognition-Primed Decision (RPD) model developed by Klein and his colleagues (Klein, Calderwood, & Clinton-Cirocco, 1986).

The RPD model (Klein, 1989; 1992) was developed to describe a phenomenon observed in operational domains: people making good decisions without comparing possible courses of action. The initial studies were done with fireground commanders. We expected that they would use their experience to cut down the number of options they compared, maybe just looking at two. We were wrong—they insisted that they hardly ever compared options. In our interviews with them about how they made tough decisions, we kept hearing about the same type of strategy. We derived the RPD model from what they told us.

There are two components of the model, situation assessment and option evaluation. The RPD model asserts that decision makers recognize the dynamics of a situation, enabling them to identify a reasonable course of action. This course of action is evaluated by imagining how it will be implemented. Experienced fireground commanders can size up a fire quickly. By assessing the type of fire, the type of structure, and the length of time the fire has been active, the appropriate response is usually obvious to an experienced fireground commander. How do you evaluate a course of action if there are no others to compare it with? One strategy fireground commanders use is to imagine carrying out the action. They run it through in their minds. If the risks are great or the course of action is complex, they may run it through several times. This process of mental simulation—mentally enacting a sequence of events—can appear also in the situation assessment phase of the model.

Figure 2 shows two versions of the RPD model. The simple version appears in the panel on the left. Here, the decision maker confidently identifies a situation as familiar. This recognition enables the decision maker to know several important things.

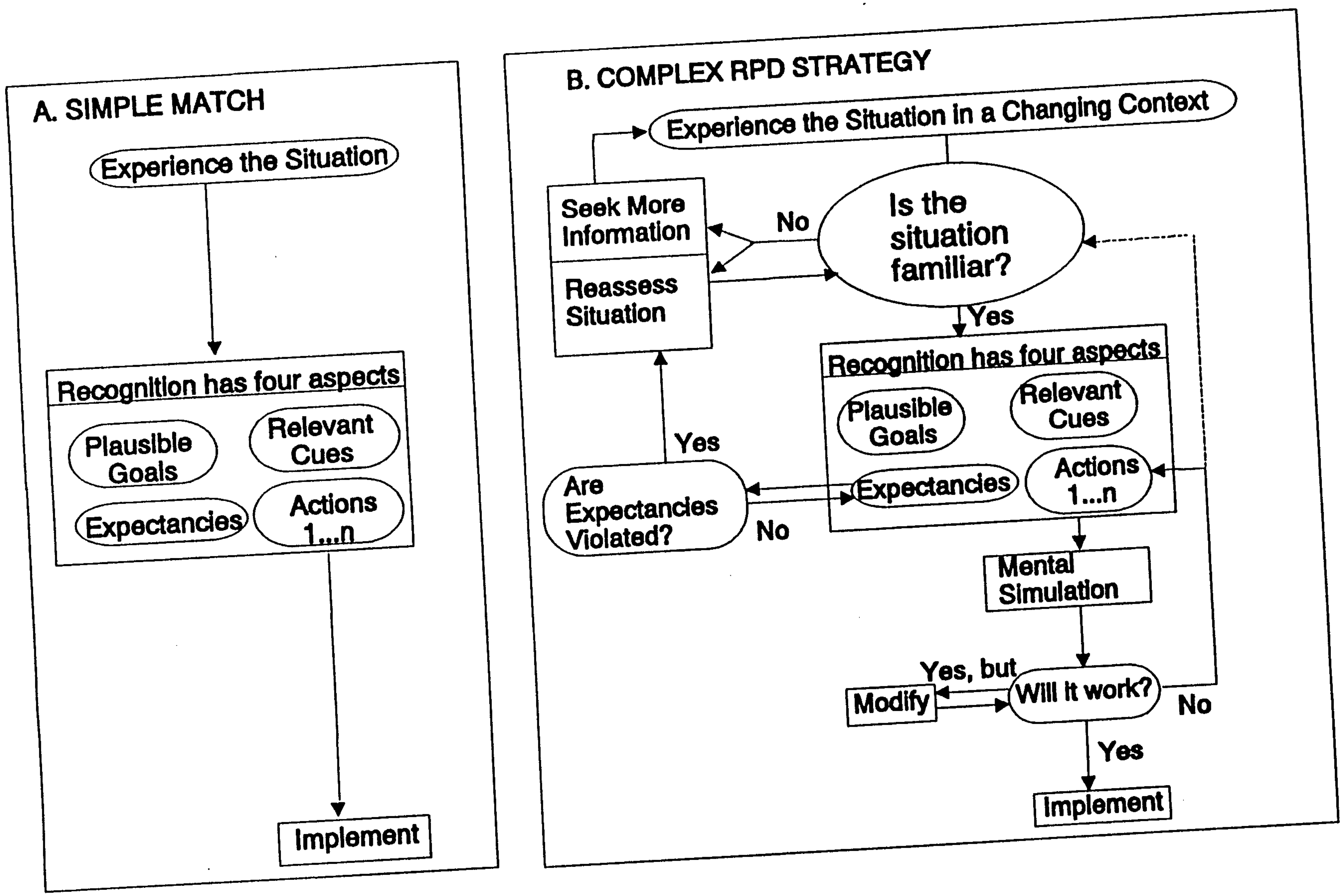


Figure 2. Recognition-Primed decision.

You know what goals make sense. You know what cues are relevant. You know what to expect so that you can be prepared. Finally, you know the typical ways of reacting.

The panel on the right shows a more complex RPD strategy. Here, the situation assessment was not so easy. The decision maker may need to acquire more information, or there may be several hypotheses about what is occurring. For instance, the commander in the F-4 example had to choose between two hypotheses. Either the aircraft were harassing , or they were preparing to attack. Decision makers use several strategies to arrive at a situation assessment or to choose among different situation assessments. One is to check the hypotheses against the features of the situation. The other is to build a mental simulation, or story, to explain the events. In the F-4 incident, the commander tried out one mental simulation, and judged that it did not make sense. He could not construct a plausible story of how a pilot would make such an attack. The other story did make sense; he based his actions on this diagnosis. Once the decision maker settles on an interpretation of the events, the same functions are accomplished as in the simple RPD model: specifying plausible goals, highlighting critical cues, generating expectancies, and identifying reasonable courses of action.

In complex cases, the expectancies can be violated, leading the decision maker to seek more information and to reassess the situation. Complex cases can also call for evaluation of a course of action. From the interview data we have collected, there seem to be two primary ways of evaluating options: checking them for necessary features and using mental simulation. Sometimes people evaluate a course of action by checking to see if it has the required features, and do not mentally simulate at all. Decision makers may consider a number of courses of action, without ever comparing one to another by evaluating the options one at a time, until they find one that works. This is a singular generation/evaluation process to distinguish it from situations where people compare options directly to each other.

In more complex cases, the decision maker may try to imagine how a course of action will work in context. This is still a singular generation/evaluation of options. If you are concerned that F-4s may be preparing to attack your ship, one obvious defense is to use chaff to distract an enemy missile. But if you play this out in your head, you may realize that your ship is between the attacking fighters and the flagship you are defending. So, firing chaff may divert the missiles away from you, but directly towards your flagship. In this case, the Electronic Warfare coordinator mentally simulated the problem and rejected the option of using chaff. In other cases, mental simulation helps to strengthen a course of action by revealing problems that can be overcome.

This discussion about RPD illustrates the importance of two types of decisions in naturalistic settings: diagnostic decisions and course of action decisions. The RPD model points out the relative importance of diagnostic decisions for people to succeed in dynamic, time-compressed situations. Previous literature focused on the phenomena of choosing a course of action. NDM research demonstrates that these course of action decisions play a relatively minor role in operational settings. Success in dynamic, time-compressed settings requires that people make accurate diagnostic decisions. The value of the RPD model is to:

- explain how people can use experience to make decisions

- describe how decision makers use situation assessment to identify courses of action

- describe how decision makers settle on a course of action without considering multiple options concurrently

- show how people using mental simulation can strengthen a course of action rather than choosing only from the set of original options

- describe how decision makers can be poised to act, rather than having to wait to complete their comparisons and analyses.

Since its development, the RPD model has been verified in many domains. For example, it describes the decision strategies of tank platoon leaders (Brezovic, Klein, & Thordsen, 1987), commanders and Anti-Air Warfare officers of AEGIS cruisers (Kaempf et al., 1992), critical care nurses (Crandall & Calderwood, 1989; Crandall & Gamblian, 1991), commercial pilots (Mosier, 1990), design engineers (Klein & Brezovic, 1986), and fire-fighters (Klein et al., 1986).

One aspect of RPD merits some attention, particularly in the context of visualization of the battlefield. This is the use of mental simulations for the evaluation of courses of action and to develop situation assessments. Several experienced Army officers have described using mental simulations to serve both functions as they plan and conduct a mission. For example, Student Text 100-9 (U.S. Army Command and General Staff College, 1986) describes wargaming as an essential component of staff analysis. The staff uses wargaming or visualization to evaluate a course of action. The text defines wargaming as a "conscious attempt to visualize the flow of a battle" (p.5-8). This cognitive activity is similar to mental simulation described by the RPD model.

Retired LTG Pete Taylor, Commanding General of NTC from 1987 - 1989, introduces a similar need to use visualization when developing an assessment of the situation prior to a defensive operation. With regard to personal reconnaissance of the terrain, the general states that it is "absolutely necessary that the commander get out and look back at their defensive position from the enemy's viewpoint" (personal communication, 1993). Thus, a commander must use a mental simulation to develop an accurate assessment of the situation. The commander should then use this assessment to build a defensive plan of action.

These two examples testify to the importance of visualization for evaluating courses of action and for building situation assessments. Furthermore, they hint at the close relationship between the concepts "visualization of the battlefield" and "mental simulation." The concept of mental simulation plays a significant role in how we define visualization of the battlefield later in this report.

Expert Skills Needed for Command and Visualization

The preceding discussion informs us about the characteristics that distinguish experts from nonexperts and about the cognitive processes that experts invoke to make decisions and solve problems. The literature presented here represents the findings of a number of researchers investigating a variety of domains. These findings from other domains provide some insight into the skills that expert field commanders might possess and how these skills might affect their performance on the battlefield. The following is a discussion of those skills that we expect expert field commanders to possess and a brief description of how these skills would be manifested. This list is not comprehensive; surely, expert commanders possess other skills and their skills may be manifested in other ways. We intend these skills to serve as a starting point in our discussions.

Experts have strong perceptual skills (Klein & Hoffman, 1993, Shanteau, 1987)

Not only are they able to perceive cues and patterns not detected by others, but they also can attribute meaning to patterns that less experienced people cannot see. For example, expert field commanders often can envision the terrain represented on a topographic map. They can look at the two-dimensional symbols on a map and mentally develop a pictorial representation of the terrain. This mental representation of the terrain enables expert commanders to envision the problems or advantages that particular terrain may afford as a battle evolves.

Experts can make sense out of chaos (Shanteau, 1985)

An expert's experience and knowledge base enable him to see meaningful patterns in confusing sets of cues, patterns that are not evident to less experienced people. This confusion is often exacerbated by the quality of information on the battlefield. There are often gaps and inconsistencies in information that a commander receives. The expert commander can assign meaning to this apparently chaotic set of data.

Experts can recognize typicality (Klein & Hoffman, 1993)

They can assess situations relatively rapidly and recognize the situation as one they have seen before or not. That is, they can classify the situation as typical or atypical. For typical situations, the expert will know what goals are relevant, what cues are important, and what actions have been successful in similar situations in the past. In addition, a sense of typicality enables the expert to develop a set of expectancies for a given situation. Expectancies represent what the commander thinks will happen and how he thinks the battle will evolve. Such expectancies not only allow the commander to plan, but they also provide a mechanism for evaluating the evolution of a battle and detecting when a plan should be altered. That is, for an expert commander, expectancies can serve as tripwires. The expert consciously establishes checkpoints and tripwires for indicating whether an operation is progressing as planned or

whether some deviation from the expected has occurred. When these tripwires or expectancies are violated, then the commander is alerted that a change may be necessary. For example, the field commander who is familiar with the threat's tactics, will be able to recognize when the threat deviates from what is expected of him, that is, when the threat changes his tactics in the middle of an operation.

The expert can create novel solutions to problems (Shanteau, 1985)

Expert field commanders are not confined to standard plans and doctrine. They are able to improvise on a dynamic battlefield. Overcoming obstacles or unexpected enemy maneuvers requires commanders to think flexibly. The unstructured environment of the battlefield provides commanders with many opportunities to use their creativity to their own advantage. This skill, needed for general command duties, is even more relevant to the area of visualization. Mental simulations that test a course of action are typically used only when the course of action is unfamiliar. Similarly, mental simulations of a battlefield scenario are used because the causal factors are too complex to simply "recognize" the outcome. The commander must "play out" the simulation and observe the effects before proceeding. This mental simulation enables the commander to envision the enemies weaknesses and where a plan might fail.

Experts can see consequences and antecedents (Klein & Hoffman, 1993)

Experts have an important advantage over journeymen in being able to visualize how situations have developed and how they are going to evolve. Experts are able to begin with one set of conditions and conduct mental simulations to determine how the conditions evolved and where they will go. For the field commander, these are important skills. These skills enable the commander to develop accurate situation assessments and to develop effective plans by simulating a given course of action to see how it will play out.

Experts can tolerate stress (Klein & Zsambok, 1992)

Stress inhibits a person's ability to conduct mental simulations and it creates tunnel vision. That is, stress reduces the amount of information that a person can process. In addition, stress acts as a competing task in that it depletes cognitive resources. Commanders must have a high level of stress tolerance to be able to think clearly. Tolerance to stress enables them to attend to the appropriate range of resources and to conduct mental simulations.

IV. DEFINITION OF VISUALIZATION OF THE BATTLEFIELD

Recently, the Army shifted training emphasis from enhancing the means of command to developing the "art of command." The Commander, Training and Doctrine Command stated that the Army "must have a vision of battle command that focuses on fundamentally competent leaders...who have an ability to visualize the battlefield gained from experience at successive command echelons" (Franks, 1993). General Franks, challenged the Army's commanders to begin an open discussion of what constitutes the art of command and to identify how the Army may ensure that its commanders at all echelons develop this art.

What is the art of command and how does it involve visualization? Visualization is a key component of the art of command. This is not a topic that is new to the Army. Army doctrine states that visualizing the battlefield is a continuing requirement for field commanders. "Command means visualizing the current and future state of friendly and enemy forces and then formulating concepts of operations to accomplish the mission" (Department of the Army, 1993, p. 2-14). Commanders must assimilate thousands of bits of information to visualize the battlefield, assess the situation, and direct military action required to achieve victory. FM 100-5 further states that command is more an art than a science, and that battle command is often guided by intuition and feel gained from years of practice and study.

Perhaps the most recent view of VOB receiving high level attention has been that of General Franks. He provided a vision of battle command "...that in the first sense focuses on fundamentally competent leaders who have the necessary intuitive sense of operational units and soldiers and ability to visualize the battlefield gained from experiences at successive command echelons" (Franks, 1993). He envisions leader teams "both horizontally and vertically united by intent and able to access broadcast data to aid in visualizing the battlefield." As a result of these views, General Franks directed his commanders to experiment with approaches that make commanders actual players as opposed to bystanders who have staffs of many assistants. In addition, he directed observer-controllers (OCs) at the CTCs to address issues of the art of command including VOB.

General Franks' commanders responded to his initiative with their thoughts about the art of command and VOB. For example, BG George Fisher, Commander, Joint Readiness Training Center, described the training challenge as the need to develop large numbers of leaders who have good intuitive warfighting instincts, can visualize and smell the battlefield, and have the agility and situational flexibility to handle the fog of war (Fisher, 1993).

MG John Robinson, Commander, U.S. Army Aviation Center, provided several insights about VOB (personal communication, 1993). First, he noted that agile, bold, creative thinkers often act on intuition, knowledge gained without rational thought. Second, the Army's training institutions face the task of unlocking, using, and stimulating the use of intuition among the Army's leadership. Third, he cautioned that the increased use of digitized information will be absorbed by the intuitive leader while confounding the imperceptible. Finally, MG Robinson

observed that as battle commands become more digitally connected, the fusion of information will be done in the brain of an intuitive commander. The staff, as it has been known in the past, may need to be trained for a very different environment.

Similarly, MG Kenneth Wykle, Commander, U.S. Army Transportation Center, made several observations (personal communication, 1993). First, commanders must be able to visualize the end state of any action and then broadcast this visual image simultaneously to subordinates. Second, close association and frequent contact with the commander enhances the ability to visualize and communicate the end state. Third, subordinates who have confidence in their commander know and understand his intent, can visualize the end state, and do not require detail or verbal guidance.

Keegan (1987) argued that the two essential elements of command are knowing and seeing. Knowing means having a general background knowledge that provides a rich context. Seeing refers to having a dynamic image of the battlefield that leads the commander to understand what needs to be done. Similarly, retired LTG Taylor posits that "it is critically important that the commander understands the enemy, and that he brings that information to the battlefield with him. Then, as he gets reports, the commander is able to visualize what the enemy is doing" (personal communication, 1993).

The Army also addresses VOB in instructional manuals. For example, Student Text (ST) 100-9: <u>The Command Estimate</u> describes VOB. The student is taught that the ultimate test of a course of action is through visualization of the battle. As they build a battle plan, staff members must wargame each course of action and compare the results. ST 100-9 describes wargaming as "a conscious attempt to visualize the flow of a battle, given friendly strengths and dispositions, enemy assets and probable courses of action, and a set piece of ground" (U.S. Army Command and General Staff College, 1986, p. 5-8).

There is remarkable similarity in the manner that all of these writers address the concepts of VOB. They all agree that visualization is a very important component of Battle Command, and that it is very difficult to do. Retired LTG Taylor stated: "At any level, the greatest challenge that a commander has is being able to see the battlefield and to visualize the battlefield. I'm talking about what he sees between his ears; seeing with his eyes is just a piece of that" (personal communication, 1993). They agree that it takes experience as well as training. They agree that it is a cognitive phenomena rather than a perceptual one, and that it relates to intuition and other ill-defined functions. Finally, they agree that visualization is a dynamic mind-picture that a commander forms from the bits and pieces of information that he receives as they are played against his expectancies based on his knowledge of conditions, the enemy, and his own forces.

These and other descriptions of VOB are remarkably consistent with the Recognition-Primed Decision model of expert decision making and problem solving presented earlier in this report. VOB is an active mental process that enables the officer to assess the existing situation and to develop and evaluate potential courses of action. Furthermore, successful implementation of this mental process depends on the experience and knowledge possessed by the officer. ST

100-9 states that "Wargaming relies heavily on tactical judgment and experience" (U.S. Army Command and General Staff College, 1986, p. 5-1). This experience base enables the officer to interpret existing cue patterns and to bridge gaps in information in ways that would not occur to less-experienced officers.

The RPD model describes this mental process as mental simulation: the process of consciously enacting a sequence of events. Expert decision makers use mental simulation to evaluate courses of action and to build a plausible explanation of the situation. That is, to build a situation assessment. Officers start with a set of initial conditions and can build a simulation backward in time to develop an understanding of how the events evolved. This serves to sharpen their situation assessment. In addition, officers may take the same set of initial conditions and build a simulation forward in time to evaluate and revise a course of action.

Thus, VOB is a form of mental simulation. There is some research literature that addresses issues of mental simulation. Klein and Crandall (in press) provide an excellent review of some of this literature and present a model of mental simulation based on the findings of their work. The next section presents a summary of this model. The following section discusses the information that a commander needs to visualize a battlefield. The final section of this chapter discusses the products that a commander can derive from effectively visualizing the battlefield.

As indicated, the concept of VOB has been discussed often within the Army. However, there are many inconsistencies in the way that the phenomena is described. One reason for this inconsistency is that a variety of similar terms are often used to describe VOB. For example, the terms image, dynamic image, vision, and mental model are all used to describe how a commander understands the battlefield. In addition, it appears that people think about visualization in somewhat different ways. A narrow definition of the term might be: the ability to mentally envision the state of the battlefield at a point in time. A broader definition might be: the ability to "see" the interplay between forces including the relationships and interdependencies among friendly units. Both definitions describe the military term "visualization" in terms of actively doing something in one's head. As we will discuss later, this concept is consistent with and can be defined by the psychological notion of mental simulation.

Our objective in this chapter is to develop a definition of VOB that will enable us to study the cognitive processes that commanders invoke to visualize the battlefield, to study the types and quality of information that are important when visualizing the battlefield, and to develop interventions that will enhance the ability of commanders to perform this vital task. This definition must be operationally significant for the Army and be grounded in the contemporary research in the cognitive sciences.

A Model of Mental Simulation

Based on an examination of 102 mental simulation descriptions, Klein and Crandall (in press) derived a general model of mental simulation. Figure 3 presents this model. A person uses mental simulation to accomplish some goal, so the first function is to identify the need

motivating the activity. For a given need, the next step depicted in Figure 3 is to specify the parameters of the simulation. The person needs to determine whether the task is to interpolate between a known initial condition and a known terminal condition, to extrapolate forward from a known initial condition (as in predicting the future), or to extrapolate backward from a known terminal state, as in trying to explain a situation. The person needs to identify the causal factors that will be used in the simulation.

The third step depicted in Figure 3 is to assemble the simulation. Many simulations in the database comprised transitions from one state to another. The purpose of the simulation was to examine the nature of these transitions. It appears that people naturally limit the number of factors and transitional states they employ in a simulation. The median number of transitions was about six, and the median number of causal factors that varied was three, with a range of one to six. So, we have represented mental simulation as an action sequence with six progressions and three operators or causal factors. Sometimes the initial state will be given, and the person will extrapolate to an end state. At other times, both the initial and terminal states will be known, and the task will be to interpolate to bridge the gap.

We have depicted the transitions from one state to another as discrete, rather than continuous. Therefore, "configuring the simulation" in one's head involves selecting a small number of variables and manipulating these over several transitions like successive frames in an animated sequence. Not all mental simulations are experienced as a series of discontinuous action states; many appear to run in a continuous action flow. But in these instances as well, the number of factors and the span of the simulation are constrained.

The internal coherence of the simulation is judged using some of the criteria listed by Robinson and Hawpe (1986) for evaluating stories: coherence, completeness/selectivity, and applicability. Pennington and Hastie (1993) have suggested that stories are more acceptable as a function of completeness, consistency, plausibility, and uniqueness. In other words, the simulation has to make sense, it has to address the important features of the situation but not drown in excessive detail, and it has to apply

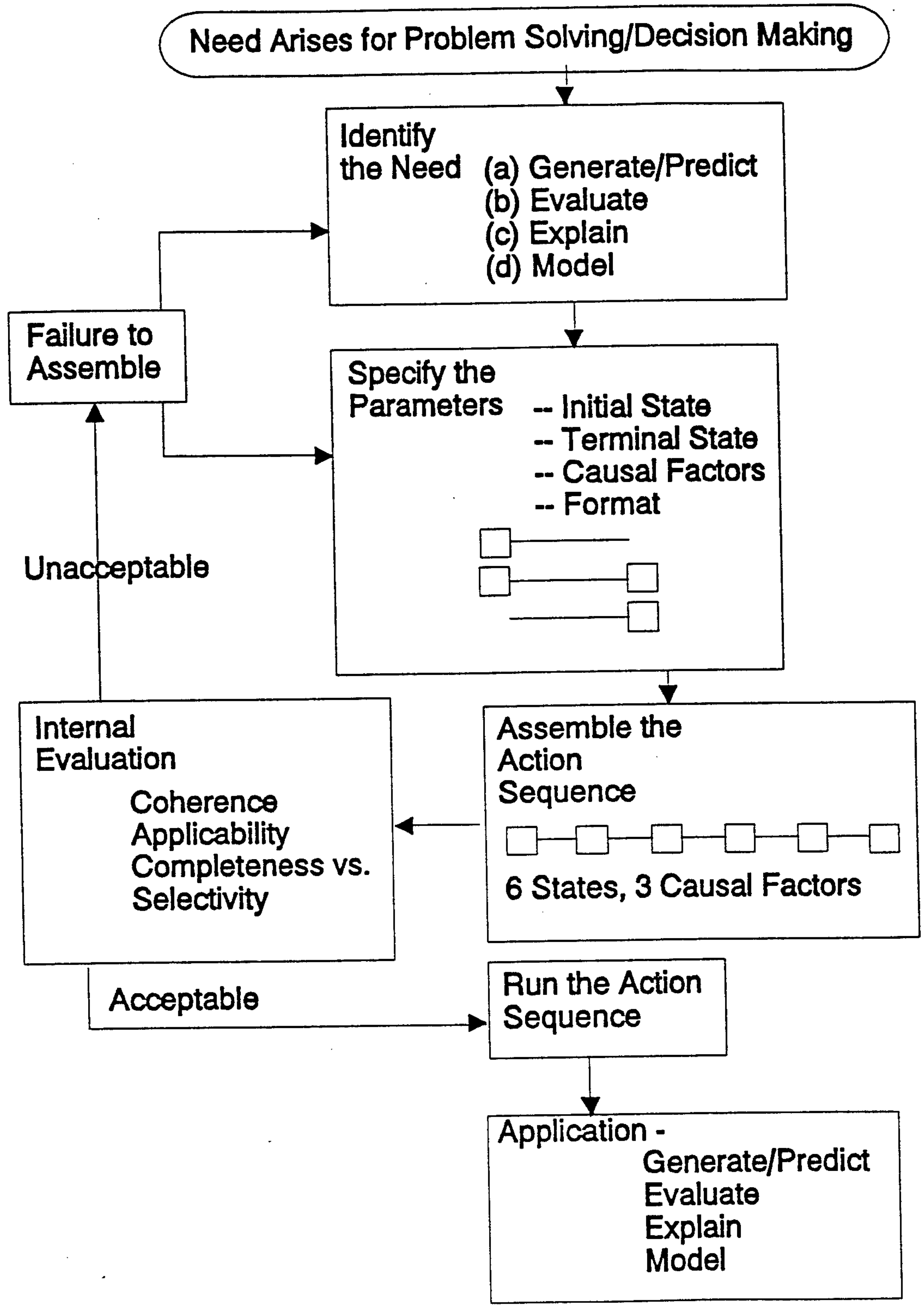


Figure 3. A general model of mental simulation.

to the goals. If the simulation fails these tests, it will be necessary to try again or to rethink the goals. If it succeeds, then the person runs the simulation and uses the information gained from it.

Figure 4 shows an elaboration of the general model. Here the mental simulation is used to generate a course of action, as described earlier. The person builds the simulation by specifying the parameters, assembling them into an action sequence, checking whether the action sequence is appropriate (e. g., is coherent, applies to the need at hand, and is sufficiently complete), runs the action sequence, and uses the run either as the plan itself or to obtain predictions.

Figure 5 shows the use of a mental simulation to evaluate a course of action, once it is generated. The functions of generating and evaluating a course of action are closely related. The only difference is that Figure 5 has elaborated some of the final steps. The running of the action sequence takes the form of reviewing each step to spot problem areas such as implausible continuations, inconsistencies, and pitfalls. These trouble spots may themselves be evaluated, using mental simulations. This is referred to as "micro-simulations" in Figure 5. Finally, the decision maker or problem solver may form a global, perhaps affective evaluation of whether the course of action seems workable.

Figures 6 and 7 show a different aspect of mental simulation explaining and modeling. Here the focus is on situation assessment rather than on a course of action. Figure 6 covers the use of a mental simulation to build an account of how an event may have evolved. Thus, it starts from the past and ends in the present. The primary difference from Figure 4 is that here, the failure to build an acceptable mental simulation has significance. It is often taken as a sign that the explanation is not reasonable.

Figure 7 covers the use of mental simulation to learn more about the situation or the phenomenon. It expands on Figure 4 by showing that the evaluation can be used to revise and vary parameters in the simulation, so that the intent is to improve and elaborate the action sequence.

We must be careful about the way we treat these processes. There are many cartoons about complex sequences that depend on a stage marked "Miracle." There are also many computer simulations that include functions such as "Understand," which, in fact, do not understand anything but merely signify the need to someday figure out what understanding is. None of the stages in Figures 3 - 7 seem to require miracles, but some of them may appear to describe a process while only naming that process. However, the descriptions in these figures offer a detailed account for understanding and studying the phenomenon of VOB.

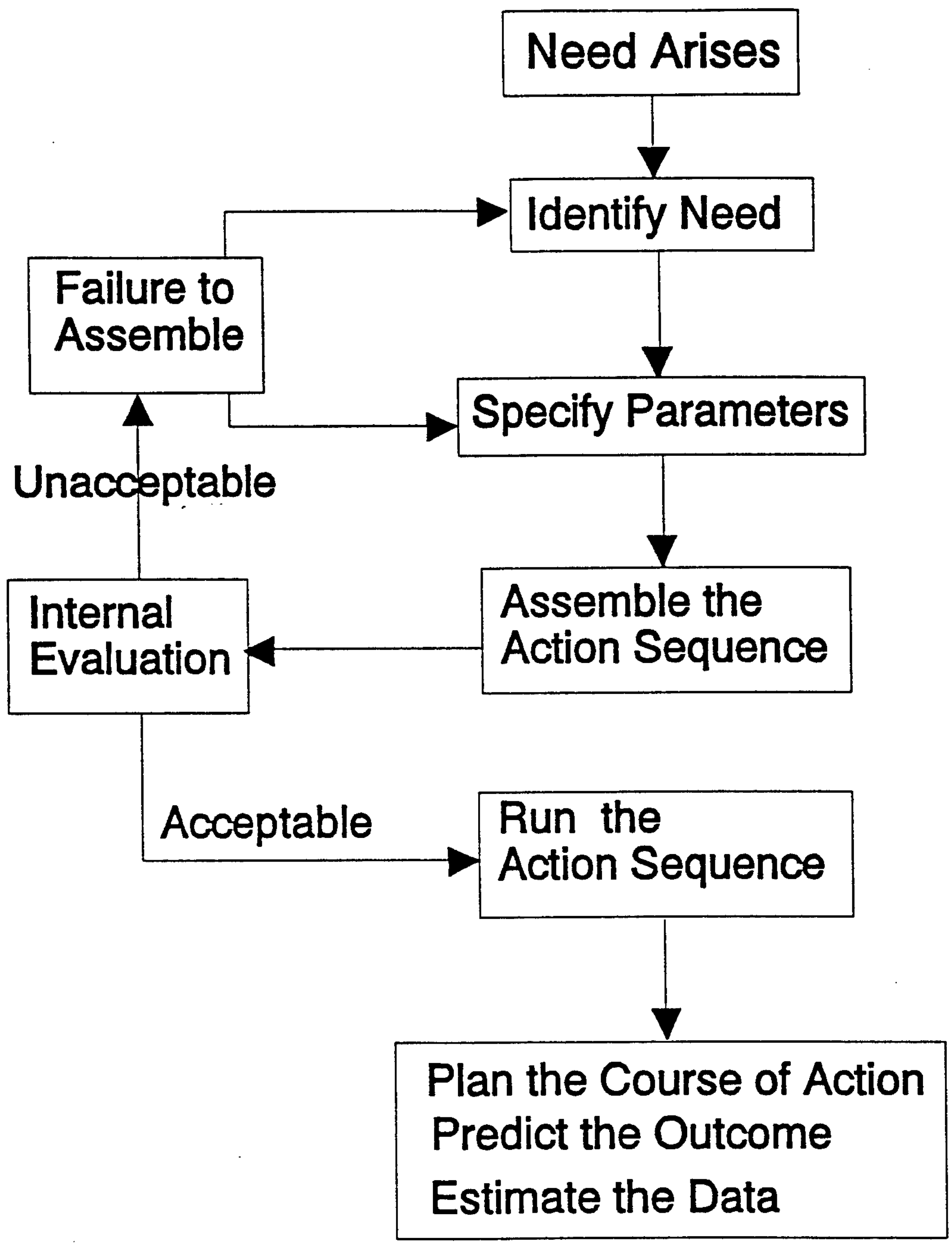


Figure 4. Generate a course of action.

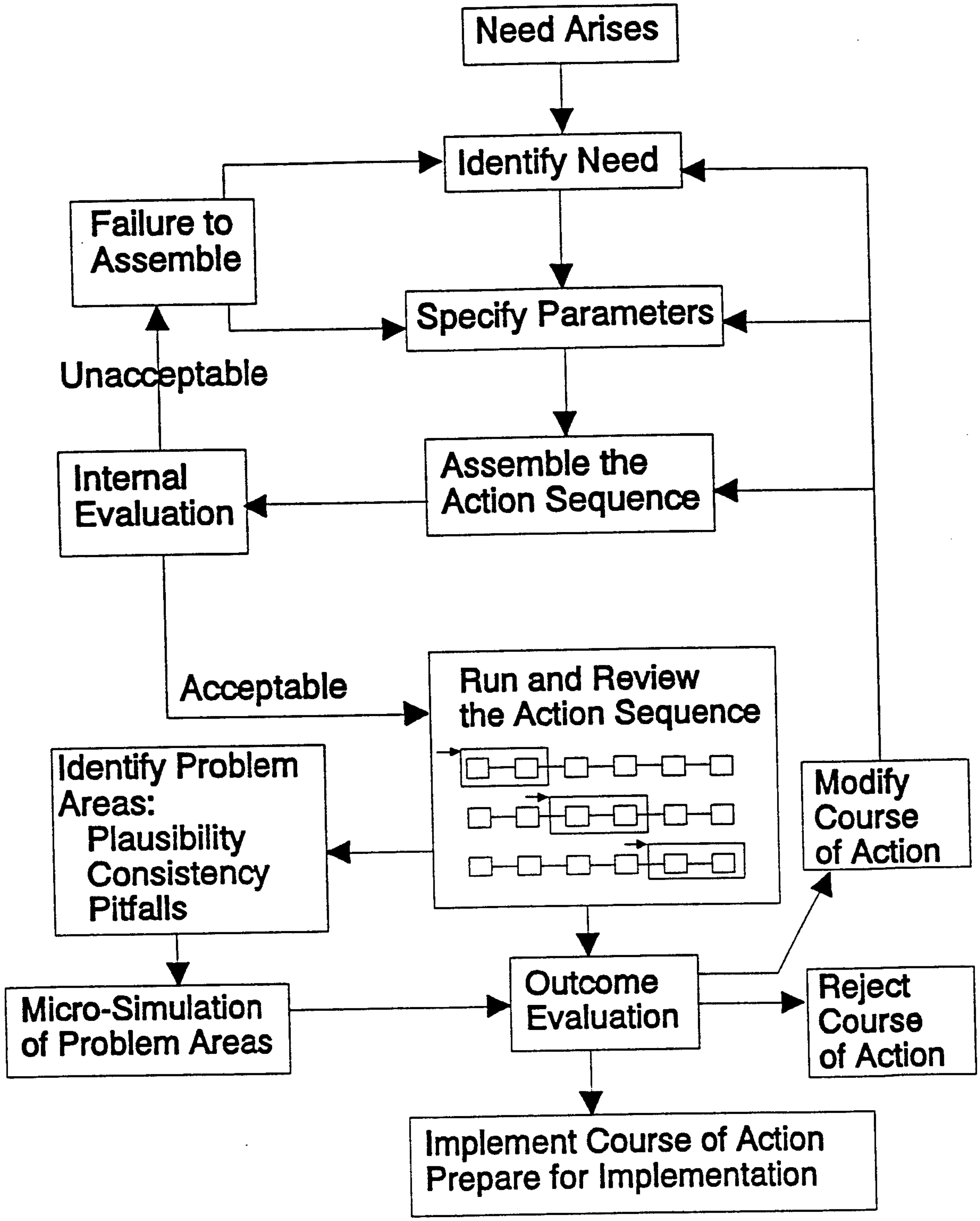


Figure 5. Evaluate and inspect risks.

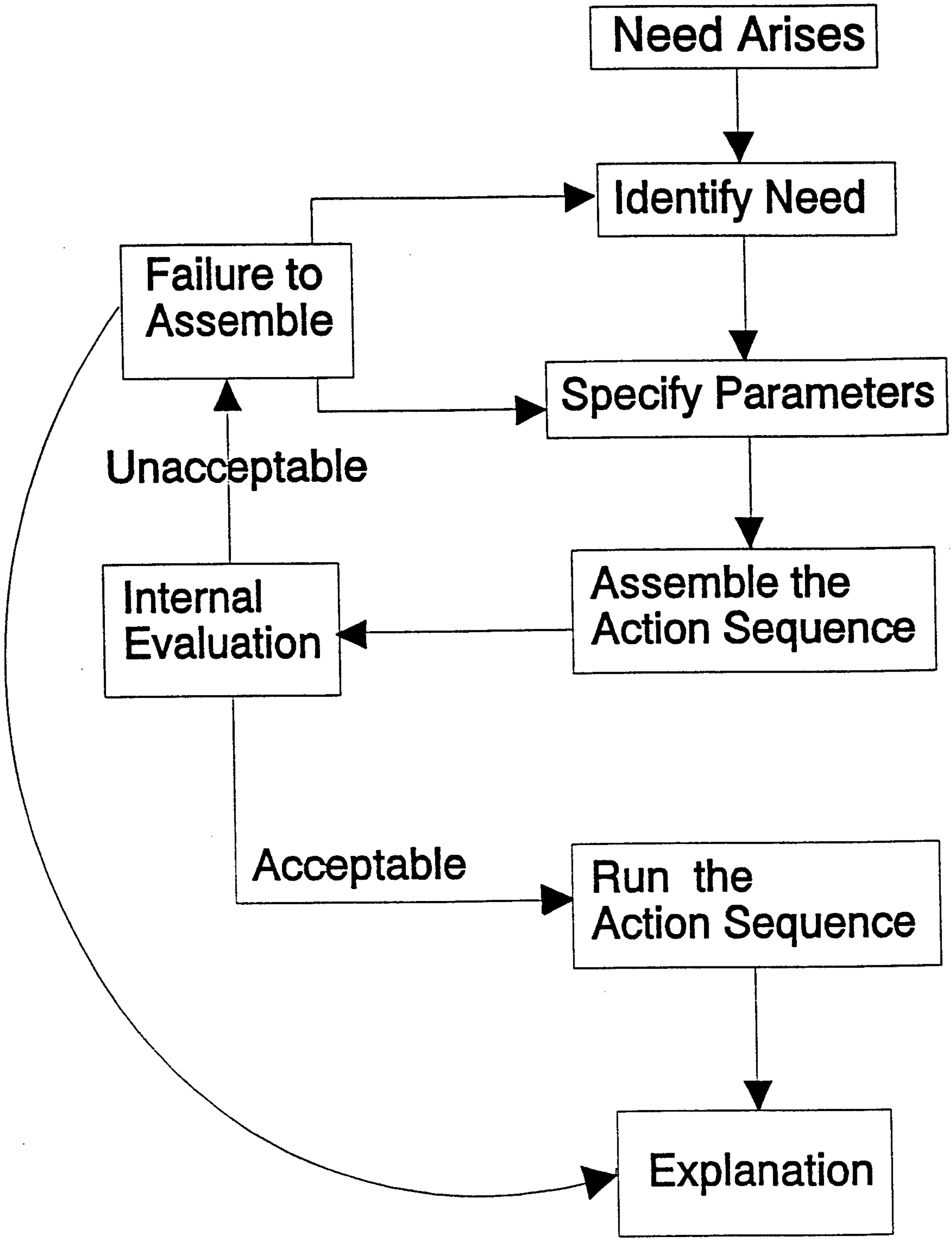


Figure 6. Explain.

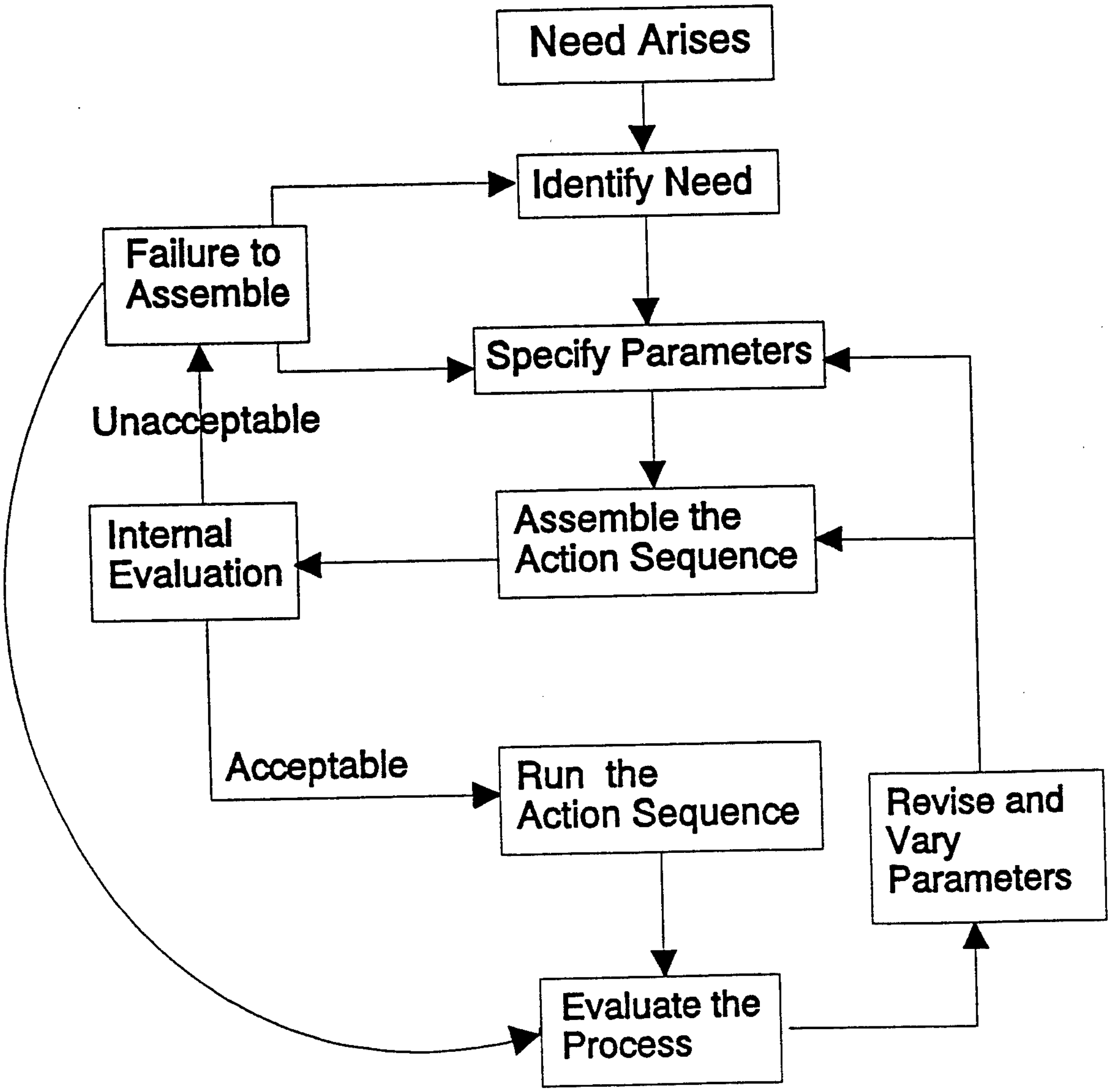


Figure 7. Model.

Information Requirements

Clearly, anyone attempting a mental simulation needs some information or cues to begin. In the case of visualizing the battlefield, the commander must invoke his personal knowledge and experience. Retired LTG Taylor states that "It is critically important that the commander understands the enemy and that he brings that information to the battlefield with him because as he gets reports he is able to visualize what the enemy is doing" (personal communication, 1993). However, on modern battlefields, the commander cannot use his own senses to "see" the entire battlefield. He must develop an understanding of what is happening beyond the range of his own body. Thus, he must rely on what he actually sees, external information provided by others, as well as what he brings to the situation.

The list of external information that a commander should or could receive is rather long. A discussion of this material is beyond the scope of this chapter. But, external information includes such factors as weather, terrain, nature and disposition of friendly forces, threat composition and disposition, and the higher-level echelon commander's intent. It should be clear that this information does not equate to the cognitive process of visualization or mental simulation. However, the commander needs such information to conduct the mental simulation. In fact, the amount and accuracy of the information provided to the commander will affect the validity and completeness of the simulation.

The modern battlefield is a highly dynamic environment. Thus, accurate information and assessments often do not reach the commander in a timely manner. Commanders often must make decisions in the face of incomplete information or conflicting pieces of information. Simulations and experience enable a commander to recognize both where information is missing and ambiguities among pieces of information. This experience also enables the commander to build stories or explanations that bridge these gaps and ambiguities. That is, an experienced commander can build explanations that logically bridge the available pieces of information. The commander can be presented with a wide array of facts and information, but he must provide some interpretation of this information. He must give some life to the facts in a way that instills some intent and intelligibility to the threat.

Products of Visualizing the Battlefield

Similar to VOB and information requirements, much of the existing literature does not distinguish the mental process from its products or outcomes. This presents some confusion about the cognitive process. Mental simulation is a distinct cognitive process that a commander can use to his advantage. Successful completion of a mental simulation can result in a number of useful outcomes. These include a thorough and accurate situation assessment, a viable plan of action, a well-defined view of his own commander's intent, and a set of expectancies describing how the planned battle should evolve complete with tripwires. There may be other outcomes as well. Each of these are described below.

An accurate and encompassing understanding of the situation is necessary for the commander to develop an effective course of action. The commander must understand the existing conditions such as weather, terrain, and the nature and disposition of friendly forces. But, he must also interpret the information available to determine the intent and the plan of the threat. One method for building such a situation assessment is to conduct a mental simulation that begins at the current point and builds an explanation backward in time of how the existing conditions evolved. Another method is to put oneself in the position of the threat commander and conduct a mental simulation of how the threat would execute the battle. These simulations require that the commander go beyond simply absorbing information provided by others. The commander must provide an interpretation of the cues. This interpretation is idiosyncratic in that it is based on the knowledge held by the commander and on his past experiences.

As described in ST 100-9, the commander and his staff develop and evaluate the plan of action through the use of mental simulations. These simulations enable the staff to move through the proposed plan step-by-step, looking for vulnerabilities and identifying steps that are not goal directed. This process allows the staff to modify the plan when required and continue the analysis. The staff can conduct such an analysis with multiple plans and evaluate their relative effectiveness to select the best plan. Thus, a major product of the mental simulation is a viable plan of action.

Concurrent with developing and selecting the plan of action, the commander can use the mental simulation to develop a set of expectancies for how the operation will evolve. Through the visualization process he will have created an image of what the threat intends to do and the actions that it will take. These expectancies can serve as tripwires that the commander may use during the course of the operation. If the threat violates any of these tripwires, then the commander may alter his course of action accordingly.

Another important product of visualizing the battlefield is a better understanding of the commander's own intent for the operation. A subordinate commander receives a statement of the higher headquarter's intent which serves as a basis for developing his intent for his own subordinates. However, a commander must use a mental simulation to derive the remaining elements of his intent. These include providing an image of the desired outcome and describing how the unit's mission fits into the larger mission. The commander must use visualization to develop an image of what the end goal is and a reasonable plan for how to get there. That is, visualization is not a component of commander's intent nor is commander's intent a component of visualization. The elements of commander's intent are derived from the process of visualizing the battlefield.

V. TRAINING IN BATTLEFIELD VISUALIZATION

Many aspects of an officer's training provide the skills and knowledge required to visualize the battlefield. In this section, we first give an overview of the officer training process, highlighting its relevance to battlefield visualization. Then we briefly describe some of the content visualization skills included in officer training.

Overview of Army Officer Training

Officer training, like all military training, is an ongoing process that continues throughout the officer's career. Most Army officers enter the Army with relevant training, whether it is from a Military Academy, an ROTC program, or other officer acquisition program. Following accession, training continues in a formal program of specialized skill training and professional development education, alternating with unit assignments.

Officer basic course. Upon receiving a commission, the new officer attends a 12-week officer basic training course. This course, conducted by a specific Army branch, trains the officer in basic skills, as well as in the art of maneuver at the platoon level. The course prepares the officer for his first assignment as a platoon leader or member of a company staff.

Officer advanced course. After obtaining some operational experience, the officer returns to his branch school to receive additional training in the skills required for command at the company level. By this time, the officer has usually achieved the rank of Captain, although he may still be a 1st Lieutenant. The officer advanced course teaches command skills at the company level and prepares the student for battalion and brigade staff duties. The length of the course varies with the branch, but has an average of 59 days (OASD(P&R), 1993). Following this course, the officer is prepared for the next assignment as a company commander or as a member of a battalion or brigade staff.

Combined Arms and Services Staff School (CAS^3). The next major training opportunity, which occurs after several years of additional operational experience, is the Combined Arms and Services Staff School. This nine-week course provides training in the responsibilities of the brigade staff, including training, managing budgets, mobilization, deployment, and preparation for combat (Naylor, 1994). The course teaches general problem solving and decision making skills that can be applied to a variety of staff activities (Lussier, 1992). Unlike the previous courses, CAS^3 is a temporary duty assignment conducted while the officer, a Captain, has a relevant staff assignment.

CAS^3 is conducted using a combination of lecture and practical exercise. Of particular concern for this report are two staff exercises that are currently being revised to reflect doctrinal changes (Naylor, 1994). The first of these is a central European scenario that is an element of the course module covering preparation for combat. This scenario is being changed to reflect the breakup of the Soviet Union, and the increasingly dynamic battlefield that is being envisioned

in new Army doctrine. The second staff exercise is the capstone exercise conducted at the end of the course. This exercise involves operations other than war in Central America. This exercise is also being modified to reflect current doctrine, as well as the current global political situation. Overall, activities potentially related to visualization of the battlefield represent approximately one-third of the time at CAS[3].

Command and General Staff College (CGSC). The CGSC is part of the Army's professional development education system. The goal of this 42-week course is to prepare officers for command and staff duties, particularly at levels of division and higher. Officers selected to attend CGSC are usually at the rank of Major, although there are some Lieutenant Colonels from areas other than combat arms. Topics include division and corps operations, joint operations, and the art of command.

Army War College. The most promising officers at the Lieutenant Colonel or Colonel rank are selected to attend the Army War College. The purpose of the Army War College is to prepare officers for command at the highest levels. The focus of the education is on national goals and national security policy. The college examines national security problems from all aspects, including economic, scientific, political, and sociological factors.

Tactical Commanders Development Course (TCDC). TCDC is a two-week course given by the School for Command Preparation (SCP) at the Command and General Staff College (CGSC) to prospective battalion and brigade commanders. Students are generally O-5 and O-6 officers. There are two versions of the course, one for battalion commanders and one for brigade commanders. The battalion-level course focuses on battalion task force commanders in Armor, Infantry, Field Artillery, Aviation, Air Defense, Engineering, and Special Forces. The brigade-level course focuses on the same areas at the brigade level, including division and corps battalions and corps brigades. Most of the students in this course at the brigade level are War College Graduates, while students take the battalion-level course before being eligible for the War College.

Introductory briefing material for TCDC states that the course is focused on "warfighting/warrior" skills required to synchronize BOSs "to produce maximum combat power at the decisive point." The general course requirements, as stated in the briefing, include the following:

- Technical and tactical proficiency;
- Battlefield experience (actual and simulated);
- Ability to visualize the battle;
- Mastery of speed, space, time;
- Common culture/common language;
- Ability to control combat systems through subordinates;
- Decision making process;

The course involves approximately 80% practical exercise and 20% formal instruction. It uses computer simulation (JANUS) to provide practice and training on dynamic aspects of command. The practical exercises cover command functions in both defensive and offensive missions.

Ten of the 25 lessons in the Brigade TCDC syllabus cover activities related to visualization of the battlefield. These lessons represent 27½ hours of instruction and practical exercise, or roughly a third of the entire course. Clearly, visualization of the battlefield is a primary focus of TCDC at the brigade level. Somewhat less emphasis is placed on visualization skills in the Battalion-level course; these skills comprise eight lessons and 19 hours, or roughly a quarter of the course.

Summary. All of the officer training courses described above address visualization of the battlefield to some extent. The nature of this training varies greatly from initial skill training courses to the Senior Service Colleges. The officer basic and advanced courses train some of the component skills that are required to visualize the battlefield. These skills are then combined to develop and execute battle plans at the brigade and battalion levels in CAS^3 and TCDC. These two courses provide training that is the most directly relevant to the commander's visualization. Training focused at higher echelons, such as CGSC, is also relevant. Finally, the War College greatly enlarges a commander's vision to integrate economic and political factors with operational considerations.

Training in battlefield visualization skills is accomplished through a combination of traditional classroom lecture and staff exercises, which may be supported by computer-controlled battle simulations. While the proportion of time allocated to exercises and simulations varies across course, the proportion of hands-on training has been increasing in the past several years, indicating that the Army perceives these methods to be very important. Their importance is highlighted by the ongoing revisions to CAS^3 described by Naylor (1994). There is a need for even greater reliance on hands-on training to enhance command skills.

Unit Training

Training continues in the units to which officers are assigned after periods of formal training. Unit training is not well documented, so the following estimates are approximate and indicate only the order of magnitude of unit training. Training consists of several types of exercises conducted from platoon to corps level, and culminates with a rotation at one of the National Training Center (NTC) or another Combat Training Center (CTC), depending on the type of unit. A specific battalion commander will probably experience only a single rotation at NTC as a battalion commander. Of course, he will have been at NTC several times previously in other roles.

Training conducted in the several months prior to a rotation at NTC prepares the unit by reinforcing the skills that are required for that exercise. Platoons will conduct approximately four field training exercises (FTXs), as well as additional situational training exercises (STXs). In addition, the platoons will participate in all FTXs at higher level. Companies will participate three exercises at that level, as well as three exercises at the Battalion level. Probably only one of these FTXs will involve the brigade staff. To supplement field training, brigade and battalion staff will participate in several command post exercises (CPXs) in preparation for their rotation to NTC.

Following participation in exercises at NTC, units will continue training to maintain readiness in mission essential tasks. Such training might involve a battalion FTX about once each quarter, and a brigade FTX about twice each year. Field training is supplemented with training using simulations, such as SIMNET, JANUS, or at the Battle Command Training Program (BCTP). BCTP is a mobile, self-sufficient, combat training center that provides training for division and corps commanders and their staffs, including brigade commanders. Because of the limited availability of simulation hardware, these exercises are not conducted more than about once annually.

Because of the difficulty and costs required to assemble a brigade-sized unit for an FTX, exercises at this level are relatively infrequent. The brigade commander must rely on his experience at lower echelons as the basis of his expertise. Consequently, it is important that the commanders at higher levels have a history of command and staff positions, so that they can obtain the experience required for their duties. Fortunately, commanders at brigade level and above tend to have continuity in command experience. That is, nearly all brigade commanders commanded battalions in previous assignments. Similarly, most battalion commanders previously held company command and primary battalion staff positions.

Content of Visualization Training

Officer training courses describe a single command estimate process, that is meant to ensure that commander's vision is properly developed, analyzed, and communicated to the staff and subordinate commanders. The command process, includes the following four activities that are directly related to visualization of the battlefield:

- Commander's intent,
- The threat integration function of the IPB process,
- Wargaming as a method for developing and analyzing courses of action, and
- Mission Rehearsal.

The following subsections describe these activities. Wargaming will be described first, because it is the most directly associated with visualization, and because the other activities all involve wargaming to some extent.

Wargaming. Wargaming is the primary method for visualization that is taught in TCDC. ST 100-9 defines war gaming as "a conscious attempt to visualize the flow of a battle, given friendly strengths and dispositions, enemy assets and possible courses of action, and a set piece of ground. It attempts to foresee the action, reaction, and counteraction dynamics of a battle (p. 4-1)." ST 100-9 further states that "Wargaming relies heavily on tactical judgment and experience" (p. 5-1). Thus, the development of wargaming skills is tied to the development of expertise.

Wargaming is used to test courses of action against likely enemy reactions, to determine the best course of action, and to refine existing courses of action to respond effectively to likely contingencies.

In conducting a wargame, the commander and his staff mentally simulate a battle in order to evaluate one or more courses of action. The wargaming procedures include several safeguards to ensure that the wargame is conducted in a fair and unbiased manner. For example, ST 100-9 contains several rules for wargaming to ensure that all advantages and disadvantages of a course of action are noted, that infeasible options are rejected, that courses of action are not compared prematurely, and that all facts are included in the wargame, not just those that support a particular conclusion. The procedures also specify that several enemy actions be considered in a wargame, including at least the most likely action and the most dangerous action.

Wargaming is conducted by the battle staff under the direction of the commander or the XO. Often the S2 (or G2) plays the role of the enemy commander, while the S3 (or G3) plays the role of the friendly commander. The wargame is conducted in a series of action-reaction-counteraction drills, each of which addresses one critical event. One of the simulated commanders makes an action and describes this action to the other staff members. The staff next analyzes possible reactions to this action. Finally, counteractions that respond to the possible reactions are considered. The action-reaction-counteraction cycle continues until the critical event is successfully completed or the staff determines that the method being considered is infeasible.

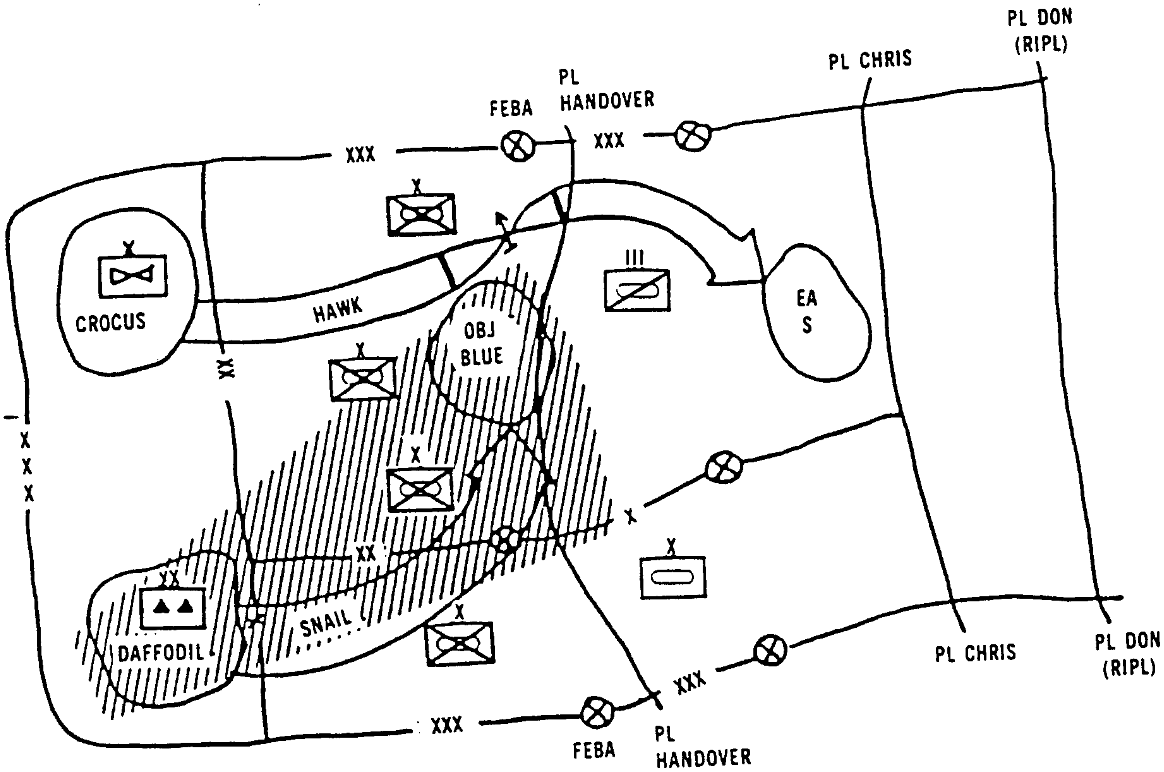
The following three techniques are used to organize the wargaming activities over an area of interest:

- The avenue-in-depth technique focuses on one avenue at a time. It is most appropriate for offensive missions, or where the terrain limits the number of avenues of approach.

- The belt technique divides the battlefield into areas that run the entire width of the sector. The critical events in a belt are then analyzed sequentially. This method is the preferred method according to ST 100-9.

- The box technique focuses on a few critical areas. It is most appropriate where time is extremely constrained. The box technique can also be used in conjunction with other techniques.

There are three methods described to record the results of a wargame. The narrative technique, shown in Figure 8 (reproduced from ST 100-9), is the most time-consuming method, but it provides greater detail. A wargame worksheet (Figure 9) provides a format to describe the actions, reactions, and counteractions that were considered in the analysis. Finally, a synchronization matrix (Figure 10) lists all the activities by time and by BOS. The synchronization matrix is emphasized in TCDC, and students must produce these matrices for both of the missions addressed in the course.



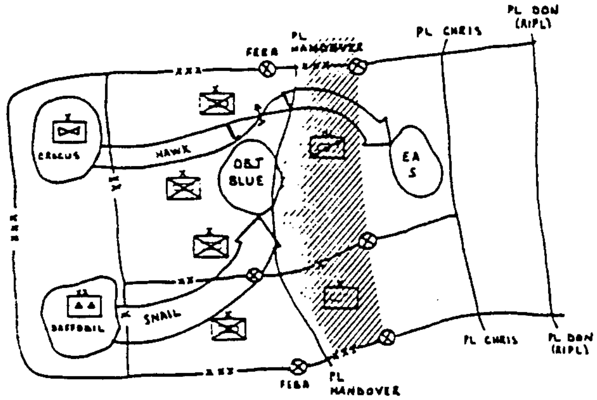
NARRATIVE WAR GAME

CORPS DEFENSE

CRITICAL EVENT: Corps Counterattack—Box 1

As the follow-on tank division approaches the FLOT, the MBA units will both have fought significant fights but will be well disposed along the FEBA. The threat will probably commit the tank division along the avenue that has produced the most significant results. We feel that this will be along the avenue just to the north of the division—spearate mechanized brigade boundary. The MBA division may have sufficient combat power to defeat this tank division if the disruption efforts of the corps deep operations campaign have been successful. While we hope that this will be the case, we feel that the threat is most likely to penetrate our defenses vic obj BLUE. The corps counterattack force, division (minus), will plan a counterattack to destroy any force making a significant penetration into this area. As this is the area where we feel the threat will more than likely come, we are well prepared for it by the initial placement of the counterattack force. The MBA division will support the counterattack by holding the shoulders of this penetration. The penetration will be shaped so that the division (minus) attacks the southern flank while the MBA division blunts the penetration. At the conclusion of this operation, the corps will defend along the FEBA with the MBA division in the north, the corps counterattack force, division (minus), in the center, and the spearate mechanized brigade in the south. Priority of engineer support to the MBA division to preparatory positions to hold the shoulders of the penetration, then to ensure mobility of the counterattack force. Aviation brigade be prepared to support counterattack into obj BLUE. ADA priority to protecting the move of the counterattack force. IEW assets confirm the commitment of the threat into obj BLUE, identify any follow-on forces.

Figure 8. Sample narrative of wargame, from ST 100-9.



NARRATIVE WAR GAME

CORPS DEFENSE

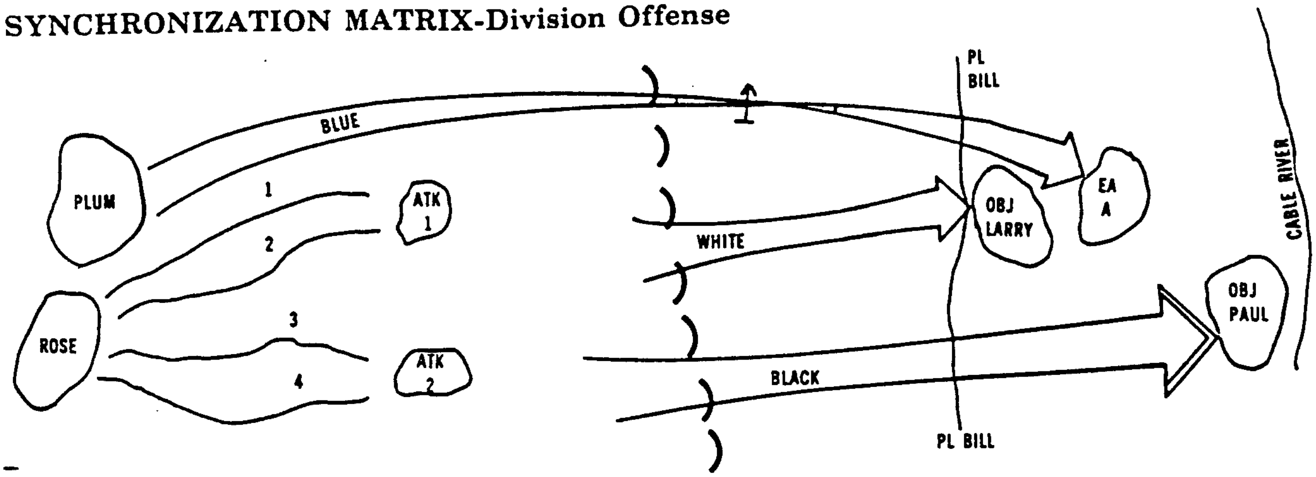
CRITICAL EVENT: Covering Force Battle—Belt 1

Sequence	ACTION	REACTION	COUNTERACTION	ASSETS	TIME	REMARKS
1	Move into positions. Remain dispersed for max protection. Monitor enemy nets. Locate CPs and FA units.	Conduct recon to find BPs and gaps in covering force units. Threat TAR from *front* and army.	Conduct counter-recon activities. Strip away army, div, & regt recon elements. Maintain listening silence. Emphasis on deception, building BPs, and FA positions for counterfire. Corps BAI program out to RIPL* slow 2d-ech forces.	ACR, maneuver bde, target acq btry, 6 FA bns, MI, ADA, engr assets.	H-36 to H-7	CFA must be portrayed as MBA. FCS to ACR & DIVARTY, priority fires to MRLs, DAG, RAGS, engr OPCON CF.
2	Prep for ground assault. Alert ADA systems for fixed wing & hel CAS. ID enemy air atk ave.	Conduct FA prep on BPs, CPs, FA locations. Jam cmd, fire nets, and ADA warning system. Atk with fixed and hel CAS. Counter air program with air and ADA.	Loc FA firing position and nets. CF and jam. Employ CA and ADA.	Tgt acq btry, MLRS, 6 FA bns, ADA Plt per bn/sqdn, TAR, counterair.	H-7 to H-hour	Priority fires to MRLs, DAG, RAGs. ADA OPCON to CF. ADA coord w/regional AD plan.
3	Threat atks with 1 regt on ave A, 2 regts on ave B, 2 regts on ave C, 2 regts on ave D although sometimes forced to 1 regt. Threat main atk on aves B & C.	ACR hold on ave A, fight main fight on aves B & C. Maneuver bde hold ave D. Must force lead divs to commit 2d-ech regts to ID main effort.	Economy of force on aves A & D, continued atks on aves B & C. Heavy FA, CAS, & commitment of 2d-ech regts to force a breakthrough.	ACR, maneuver bde, 6 FA bns,CAS.	H-hour to H+10	CF must hold on aves A & D. Strong fight on aves B & C cause threat to deploy 2d-ech regts.
4	Threat commits 2d-ech regts of 1st-ech div on aves B & C. Cont economy of force on aves A & D.	ACR fights main fight on aves B & C. Corps control of CF fight difficult. Must now allow exposed flank between the 2 CF units. MBA units prep for handover.	Threat presses hard to force breakthrough. Attempt to find handover and disrupt transition to MBA fight. Attempt to break seam between ACR and maneuver bde.	ACR, maneuver bde, 6 FA bns, CAS, spt from MBA units.	H+10 to H+15	MBA units prep for battle handover. FA plans for displacement of MBA.

*reconnaissance and interdiction planning line (RIPL)—A phase line which defines the corps area of responsibility. The RIPL is drawn on the operations map to delineate the area forward of the corps fire support coordination line into an area for the corps to target BAI missions short of the RIPL and an area for the army group/allied tactical air force to target air interdiction (AI) missions beyond the RIPL. (This is a NATO term only.)

Figure 9. Sample wargame worksheet, from ST 100-9.

SYNCHRONIZATION MATRIX-Division Offense



Time	-14 hr	-12 hr	-10 hr	-8 hr	-6 hr	-4 hr	-2 hr	H-.5 hr	H hour	+6 hr	+10 hr	+12 hr	+14 hr	+22 hr
Enemy Action			threat monitors movements continue def prep					counter btry		fights from 1st belt psn	defend in 2d belt RAG dir fire	res moves to atk/block main atk		
Decision Points											[1] launch deep atk			[2] cont atk
MANEUVER: Deep												avn bde atk res vic EA A		
MANEUVER: Security	recon routes secure fwd areas				sqdn moves 3d on rts 3 & 4	(refuel)			cav sqdn moves		prep to screen rt flank		screen rt flank	
MANEUVER: Close			bdes move rts 1 & 2, (refuel) 3 & 4			lead bdes move to LD/LC			cross LD/LC		secure obj LARRY bde penetrate 2d belt pass res		atk obj PAUL	secure obj PAUL
MANEUVER: Reserve				bde moves 2d on rts (refuel) 3 & 4			bde moves				continue atk to obj PAUL			continue atk or def
MANEUVER: Rear	avn bde Level III response									risk in rear area avn bde prep deep atk				
Air defense	wpns HOLD		wpns TIGHT	protect rts & refuel areas		Protect move to LD/LC	protect lead bde		wpns FREE					spt def
Fire support		move to fwd fire psn			coord w/support arty			fire prep	provide DS/GS spt		atk RAG Fire SEAD			spt atk on obj PAUL
IEW					latest threat LOC			find RAG & threat res		confirm loc threat res	confirm move of threat res			loc threat beyond obj PAUL
Engineer				maint rts				spt to lead bde mob on axis			maint on MSR			prep def or atk
Sustainment		Refuel & maint units move			refuel & fix in atk pos			refuel & maint units to MSB			resupply bde on obj LARRY			resupply obj PAUL
C2	coord cross LD/LC main. AA Rose			TAC CP with lead bde						main plans cont atk	main prep to move			main CP moves

Figure 10. Sample synchronization matrix, from ST 100-9.

Threat integration. One function of the IPB process, threat integration is also related to visualization of the battlefield because it provides an integrated picture of the enemy, and also relies on wargaming. In a sense it is visualization of the battlefield from the enemy's perspective.

The newest version of FM 34-130, currently in draft form, has renamed this function "Determine Threat Courses of Action (COA)." It has also reduced the total number of IPB functions from five to four by combining terrain and weather analysis into a single function entitled, "evaluate the battlefield's effects on COAs." This function includes the following five activities (FM 34-130, p. 3-65):

- Identify the full set of rational courses of action available to the threat.
- Consider wildcard courses of action.
- Evaluate and prioritize each course of action.
- Develop each course of action in the amount of detail time allows.
- Identify initial collection requirements.

Course of action development is an activity that produces a situation template describing each enemy course of action. It is analogous to the development of friendly courses of action that are part of the command estimate process. A situation template describes graphically the expected threat dispositions resulting from a particular COA. The situation template is developed by applying knowledge of enemy doctrine, represented in a doctrinal template, with specific constraints imposed on enemy activity by the environment and by friendly forces. Situation templates provide a starting point for wargaming friendly courses of action.

Although the situation template is the primary product of the threat integration process, other products may also be developed, depending upon the time available for analysis, the needs of the commander, and other factors. An event template shows named areas of interest for further information collection. These named areas of interest are geographical areas in which it will be possible to observe enemy activities that will either confirm or deny hypotheses about enemy courses of action. The event matrix lists the critical events to be observed. In addition, a more detailed description of an enemy course of action, represented as a narrative or a synchronization matrix, may be produced.

Wargaming can be used for threat integration, as well as for earlier IPB functions, such as terrain analysis. The Draft FM 34-130 describes a procedure for wargaming that is essentially the same as the procedure described in the previous section, with an emphasis on the role of the intelligence officer. In addition, it describes how to use the results of wargaming to synchronize intelligence activities and prioritize intelligence requirements. These functions are accomplished by producing an intelligence synchronization matrix, which expands the intelligence portion of the overall BOS synchronization matrix.

A final point to make is that since the IPB process is a continuous process, wargaming will occur repeatedly over the course of a battle. Draft FM 34-130 stresses the need to conduct abbreviated wargames as the battle progresses and new intelligence arrives that confirms or disconfirms hypotheses about enemy COAs. This "mini-wargame" provides a mechanism to modify existing plans based on current information.

Commander's intent. Commander's intent has not received great coverage in doctrinal manuals. It is mentioned in ST 100-9, but there is no guidance given to the commander on how to formulate his intent. The new Final Draft FM 100-5 (January 1993) devotes a page to commander's intent, and gives examples of intent statements at several different echelons. However, this document also gives little guidance regarding how intent is formulated, except to state that it is based on the mission analysis and command estimate processes.

The lack of formal doctrine describing commander's intent has led to some variability in the content and use of terms in describing intent. In the interviews conducted by Lussier and Litavec (1992) with graduates of the battalion-level TCDC, the commanders recommended the increased use of standardized terms, such as blocking, turning, and fixing, defend, and destroy. They also suggested increased standardization of graphical displays. The course material we reviewed comes from a later date than the review by Lussier and Litavec, and seems to have incorporated some of the recommendations of this review.

TCDC course material gives some characteristics of effective statements of commander's intent, as well as guidance to the commander in developing intent. This material suggests the following four tools to be used in developing commander's intent:

- METT-T,
- Battlefield framework for offensive and defensive operations,
- The forms of maneuver, and
- Battlefield operating systems.

The first tool, METT-T, provides the commander cues for what he should think about when developing his intent. It also indicates what information the intent (and the commander's guidance, as well) should communicate to his staff. Information relating to METT-T, such as the restated mission, preliminary situational templates and modified combined obstacles overlays, a graphical depiction of forces available, and the mission time line, should be posted so that they can be examined by the staff. The commander can give preliminary guidance using these displays. The commanders intent and guidance will then formalize the information that was already made available to the staff.

The battlefield framework describes the kinds of operations that are conducted for a particular class of mission. This framework provides the commander with the scope of information that should be covered in his intent statement in his guidance to the staff. For example, one element of the defensive framework is reserve operations. The commander's guidance in this area should address the size and the location of the reserve force.

The forms of maneuver (e.g., frontal attack, penetration) to be employed to accomplish the mission should be part of the commander's intent. The chosen form of maneuver should be expressed in standard terminology, to avoid confusion.

Finally, the BOS provide a way to summarize the commander's guidance and to ensure its comprehensiveness and completeness. Statements about specific BOS are generally too specific to be included in the commander's intent, but they may be included in the guidance.

Rehearsal. A rehearsal is similar to a wargame in that it is a simulation or "walk through" of a particular mission. While wargaming is conducted to specify and refine a mission plan, rehearsal is conducted to communicate the plan to subordinate commanders. Thus, a brigade rehearsal is led by the brigade commander. Other participants include subordinate commanders and the brigade battle staff.

The purposes of rehearsals are to reinforce the concept of operations; improve understanding, responsiveness, and synchronization; identify contingencies; verify responsibilities, clarify backup procedures, and refine the mission plan. Rehearsals can vary from a simple briefback of the plan to a complete run through of the plan on terrain similar to the actual terrain in the area of operation. No matter how it is conducted, rehearsal is viewed as a key step in the preparation phase that can communicate the commander's vision to subordinate commanders.

VI. FURTHER INVESTIGATIONS AND RESEARCH IMPLICATIONS

This report has presented discussions concerning future battle commanders' training needs as they relate to VOB and expertise. In reviewing literature on emerging doctrine and technologies, the nature of expertise, and current Army training programs we have attempted to develop a definition of VOB. These reviews have naturally led to implications for future research that will lead to a more thorough understanding of expertise and its role in visualization.

Building on previous discussions that have characterized VOB as an active mental process that depends on knowledge and expertise, this final section presents research implications and questions in the area of training expert skills, specifically expert decision making, and assessing battlefield visualizations. The development of training interventions aimed at expertise begins with an investigation of the cognitive skills that constitute expert decision making. As (effective) VOB is largely a component of expertise, we conclude the chapter with methods for assessing commanders' VOB. We then summarize the recommendations in terms of two research thrusts.

Acquiring Expert Skills

From the review of the expertise literature and our experience gained studying tactical domains, we identified the high-level skills of expert commanders. We believe that each of these skills are important for field commanders to excel and that these skills distinguish between expert and journeyman performance. An important issue, then, is how to create experts from journeymen. As in other domains, command expertise is a limited resource on the battlefield that needs to be fostered and propagated through the command staff. This can be accomplished in at least two ways. One approach is to develop and field external technological supports, such as those described in the section on emerging technologies. The second approach is to enhance performance through training. What kind of training is needed to push adequate commanders to the higher level of performance that characterizes expertise?

It is important to note that we are interested primarily in the transition from competent performers (journeyman) to experts. We do not anticipate encountering novices at the field command level. Virtually all of the officers at this level have received considerable training and experience. Thus, we will concern ourselves with issues concerning how to identify the skills that characterize expert commanders and how to instill these skills in competent, but less experienced, officers.

Decision Making

The key to effective interventions is understanding the decision requirements of the command tasks and the underlying cognitive skills that support these requirements. In order to train and support a commander's decision making and problem solving, we must have a thorough understanding of the decisions that the commander makes and the cognitive processes that the commander invokes. The research questions related to decision making include:

- What are the requirements of battle command decisions
- What cognitive skills are needed to address the requirements
- What training interventions will support battle command decisions

It will be important to understand the requirements of particular decisions related to battle command. The following are requirements that generally apply to decision making:

- specific problems to be solved (finding a set of actions to achieve a goal)
- specific decisions that must be made (selecting one course of action from several alternatives)
- environmental cues detected
- patterns of cues interpreted
- factors considered to interpret cue patterns
- methods used to generate alternative courses of action
- cognitive processes invoked to reach situation assessments, to evaluate alternatives, and to select courses of action.

These general requirements serve as a starting point but must be better understood in the context of battle command. For example, we could conceive of the specific problem to be solved as the basis for the development of commander's intent, and the specific decision to be made, the selection of the optimum course of action from the various generated with/by his staff. The environmental cues detected may become the commander's "key reads," and so on. For measurement purposes, it will be important to know the extent to which these requirements vary or interact under time constraints, or other aspects of a dynamic battlefield.

Cognitive task analysis. Cognitive Task Analysis offers an effective method for studying and understanding the decision requirements of command in tactical domains. For example, Kaempf, Wolf, Thordsen, and Klein (1992) used CTA to identify the decision requirements for anti-air warfare command and control in the AEGIS Combat System. These decision

requirements were then used to develop human-computer interface (HCI) features that would support the commander's decision making in time-compressed situations. Similarly, Klinger, Andriole, Militello, Adelman, Klein, and Gomes (1993) studied the decision requirements for command and control in the AWACS aircraft to develop HCI enhancements for the Weapons Directors' station.

CTA offers an effective means for understanding the decision requirements of battle commander decisions. Such an analysis also can be used to delineate the distinctions between expert commanders and less experienced commanders. These distinctions then could be used as the basis for developing training objectives. A productive approach would be to focus on a subset of battle command decision requirements, come to understand the cognitive skills associated with that subset, and identify expert - journeyman distinctions before proceeding to the remaining requirements

Kaempf and Klein (1993) described a set of cognitive skills that are required for expert decision making in a variety of domains. Not all domains require the entire set; other domains may require other skills. A CTA is needed to identify the skills required for any specific domain. However, we believe that specific training interventions designed to address these skills will enhance decision making and problem solving performance of field commanders. Examples of these cognitive skills include the following:

- mental simulation
- time horizon
- metacognition
- detecting anomalies
- experience base and analogues
- mental models or representations of complex systems

What is needed is a set of training methods designed to enhance the cognitive skills derived from CTA. Again, Kaempf and Klein (1993) addressed this issue. They identified a set of training methods designed to enhance decision making and problem solving for aircraft flight crews. These methods included:

- Building an experience base through directed, manufactured, and vicarious experiences. The objective is to transfer experience from experts to journeymen without leaving experiential learning to chance.

- Designing and implementing decision-centered scenarios. Such an approach to scenario design ensures that the trainee must make choices and solve problems that are operationally relevant.

- Conducting exercises to extend time horizon. Such exercises teach trainees to use mental simulations to think ahead, to anticipate problems, and to revise their plans of action to avoid anticipated problems.

- Building mental models of complex systems. Experts need a conceptual framework for building assessments and for conducting effective mental simulations. This training contains constructive activities in which the trainee must invent solutions.

- Providing cognitive feedback. Following the end of a training session, the trainee is probed about what happened during the session and receives feedback about goals, cues, and judgments.

These methods serve to describe general features of training strategies and provide a good starting point for developing training interventions for field commanders, once situated in the battle command context. There may be others that will be more effective or efficient. The field of Naturalistic Decision Making and the methods of CTA provide us with the models and methods needed to study these issues and to develop interventions that will enhance performance on the battlefield.

A potential forum for investigating expert decision making, using NDM techniques, is the NTC. In the coming year, select rotations will focus on the integration of semi-automated forces and advanced sensor information with the training rotation. Termed the "Virtual Brigade," these exercises will lead to a definition of those training tasks which can be effectively trained in simulation exercises and those that require actual field training. These exercises will offer a wealth of captured information related to decision making and VOB.

Recognition-primed decision model. There are several areas for further investigating decision making, using the RPD model as a basis. A particularly relevant area is the relationship between time and space, two dimensions which anchor the battlefield. These dimensions, and how they interact with certainty about enemy action, or degree of risk, are prime drivers in any commander's decision making process. The application of the RPD model to these dimensions would serve to bound initial investigations in a meaningful way. The RPD model currently has four levels: simple match, evaluating a COA, diagnosing a situation, and generating a new COA.

Level 1 is the simple match, which holds for automatic, simple, and very time pressured conditions. It is the most frequent strategy, but the least interesting.

Level 2 involves using mental simulation to evaluate a COA. Here, we can use our understanding of mental simulation to predict that commanders and their staffs will evaluate plans and COAs using a small set of causal factors (about three -- for example, time, distance, and risk)

and will project forward only about six transition states. These hypotheses can be tested. Moreover, they raise questions about whether people at different experience levels differ in the complexity of their mental simulations. Further, the models developed on mental simulation may have implications for the way one would design the interface to a battle planning workstation, to help the planner, mentally simulate the implementation of the plan and keep track of the different contingencies that might arise.

Level 3 involves using mental simulation to form a situation assessment, by diagnosing anomalies or choosing between different hypotheses. Here we are particularly interested in a Gestalt-like phenomenon whereby a person works to make sense of a set of cues and forms a situation assessment (diagnosis), and thereby becomes locked into that situation assessment. A number of researchers have commented on this type of fixation on a situation assessment (e.g., Doherty, 1993; Koriat, Lichtenstein, & Fischhoff, 1990). Usually, the fixation is seen as a bias, perhaps a form of laziness whereby the person neglects to consider other perspectives. The remedy is to require the user to adopt an alternative perspective. Usually, this reduces or eliminates the fixation.

Yet recently, Michael Doherty at Bowling Green State University has obtained strange results. When asking subjects to consider an alternative perspective—the subjects did worse on the task. Doherty has speculated that when the task is to choose between familiar but competing situation assessments, then it is useful to take the other perspective. However, if the cues are complex and the difficulty is in formulating a situation assessment in the first place, then asking for an alternative perspective is too confusing, and disrupts performance.

This suggests that for complex situations, the knitting together of different cues works almost like a Figure/Ground perception. Remember the Necker cube, which could only be seen in one way at a time. Recall the old lady/young lady picture, which similarly created a fixation since the initial interpretation actively prevented seeing the picture another way. The critical cues, being assigned their values ("this is the old woman's nose, and this is her eye"), were unavailable for counter assignments ("this is the young woman's dress, and this is the feather in her hat"). In diagnosing a battlefield picture, staff members may be similarly captured by the initial interpretations they form. Fixation, then, would not stem from laziness or perversity or bias, but from the perceptual qualities of the task, and the perceptual/cognitive characteristics of the planners.

In fact, current Army symbology, based primarily on Cold War scenarios, provide us with ample material for investigation of these perceptual phenomena. Given a topographic map marked with, e.g., brigade boundaries, company sectors, avenues of approach and a primary objective, maneuver commanders will interpret that situation with little variability. Alternate interpretations are nearly impossible. Standard symbology of the linear battlefield may not accommodate the changing threat and modes of operations. Thus, not only might that symbology be inadequate, but it could possibly hinder effective visualization and interpretation of the situation.

This offers an interesting investigation topic: the discovery of the major drivers that "close" a situation assessment, making it resistant to alternative views. We might also try to identify the situational features that are most resistant to dual interpretations. These types of investigations could have important implications for the formatting of interfaces that help people retain perceptual and cognitive flexibility.

Level 4 of the RPD model is the application to problem solving and option generation. An investigation of the following questions would be help to elucidate intervention requirements. These questions also could be used to contrast differing levels of expertise.

- How does a problem solver detect anomalies?
- How does a problem solver judge the urgency of a threat?
- How does a problem solver judge the solvability of an approach?
- How does a problem solver structure the problem by identifying a fragmentary action sequence, either a central sub-task or a key opportunity or leverage point?

Assessing Commander Visualizations

Given that VOB is an important component of battle command and that effective visualization depends on knowledge and experience, a means for assessing visualizations is an important first step for understanding the differences that exist between more and less experienced commanders. The following section presents some ideas for assessment, focusing on accuracy. *For the purposes of this discussion we will define accuracy in terms of how well the "product" of visualization reflects actual battlefield events.* The goal of assessing the accuracy of commanders' visualizations is to answer some of the following questions:

- How accurate are commanders' assessments of the current situation?
- What implications do inaccuracies in current situation assessment have on predicting future situations?
- How does the accuracy of commanders' visualizations degrade with time?
- What kinds of events are most often ignored by commanders in visualizing the end state? How do the commanders respond to these unforeseen events?
- What are the ways to help the commanders to visualize the battlefield better? How can better training or job aids improve their performance?

Knowing the answer to these questions has obvious applications to diagnosing performance problems and designing training. Once the answers to these questions are understood we can begin investigating the differences between more and less experienced

commanders. We would do well to conceptualize these degrees of experience along a continuum that had company commanders (and below) at the less experienced end and brigade commanders (and above) at the more experienced end.

Hypotheses concerning the assessment of visualizations would revolve around the relative extent to which commanders consider information about the friendly situation, the enemy situation, and environmental and terrain factors. This research could incorporate methods based on NTC data, simulation exercises, battle simulations such as JANUS, or specially constructed planning scenarios.

Most research on unit performance measurement has sought a measure of that which summarizes performance over the total mission. However, visualization of the battlefield is a process of mental simulation. Consequently, the result of battlefield simulation (like any simulation) may be viewed as a list of events that the commander expects to occur during the battle. We would benefit greatly from an accounting of how the accuracy of the visualization changes with time when we assess the products of battlefield visualization. It is likely that the commander will be able to visualize the current state (or near-term events) with fairly high accuracy, but that this accuracy will decrease over time, relative to the far-term events. This loss of accuracy may be due to gaps in intelligence information, incomplete extensions of the original context, failure to consider important contingencies, or merely "drift" caused by the accumulation of relatively minor effects.

For example, during the course of a battle a commander continually modifies and refines his VOB, as events unfold and he accumulates more information about those events. Thus, visualizations are more likely to reflect near-term events than far-term events. Continual assessment of visualization product(s) over the course of the battle should provide verification of this as well as insight into the visualization process, providing answers to the previously-posed questions.

A second beneficial area for research is to develop methods that can be used to predict the course of a battle in much the same way that a commander does, that is, by a form of simulation. Such a method would make a series of predictions from the current situation to a slightly later time. The overall predicted course of the battle might then be obtained by combining the individual predictions in the series. Such simulations could help identify "high payoff" predictors -- those factors that most significantly predict events.

This method may be contrasted to former methods, such as Rakoff, et al. (1991) who attempted to predict the final state from the current situation early in the battle. Since Rakoff, et al. looked at a single snap shot of the battle, they were unable to gather enough data to build a reliable prediction method. However, in a "simulation-based" prediction method, each battle could provide many points for model development. For example, NTC records the position of each weapon system every five minutes. A simulation-based prediction method could be built to make predictions five minutes into the future. Such a method could be developed and validated on the vast wealth of information about individual weapon systems and unit performance that is available in the NTC data base.

VII. RESEARCH THRUSTS

Two parallel lines of research need to be conducted. One thrust is the analysis of the cognitive processes of expert commanders. This research can use the methods of cognitive task analysis and the measurement approaches, described in this report, to identify the factors involved in command decision making, the cognitive skills commanders employ, as well as specific battlefield stimuli and stimulus patterns that are critical to their decisions and actions. Complex, realistic situations can be developed for experiments using materials from Combat Training Center exercises and from appropriate simulations. Realistic context and complexity are important because these provide the level of detail required for experts to recognize "typicality", to form "expectancies", and to detect "anomalies" that are contrary to their expectations.

If CTC training battles are used, participants in the experiments can be presented with some or all of the information available to the actual commander, or even with supplemental information. Time pressure may be used as a variable. The information the participants use and their reasoning strategies can be determined. Interpretations and predictions by the participants can be compared with what actually occurred on the CTC battlefield. Information to the participants can be updated appropriately and realistically, and their interpretations and predictions likewise updated. Computer displays using National Training Center data, as well as data from upcoming tryouts of prototypes of new equipment for "digitization of the battlefield", can be incorporated to determine how this information is used and how it helps the participant in the experiment to visualize the battlefield and to make timely and accurate decisions.

If simulations are used, the participant in the experiment may be able to influence, through his decisions and actions, the actual course of the battle. Scenario-driven "probes" may be incorporated to present specific problems to the participant so that his reactions can be observed and measured.

Several approaches can be used to select "expert" and "journeyman" commanders. The simplest is to use junior and senior officers, and perhaps to supplement this with requirements for certain kinds of experience and training. Another approach to identifying expert commanders is to ask senior officers to (anonymously) nominate other officers whom they consider "outstanding battlefield commanders" and ones who can "visualize the battlefield." They can, as well, be asked to describe the criteria they use and to provide their recommendations on training and experiences for developing the art of battle command. Demographics and other kinds of data can be obtained for the nominated officers. These data may provide some insights into their characteristics, training, and experiences. The nominees will, as well, provide a pool of "experts". Some officers from this pool can be used in the more detailed cognitive task analyses and experimental investigations. This approach would also give access to the accumulated wisdom of senior officers on how to select, train, and develop effective battlefield commanders.

Outlines for three experiments are contained in Appendix C.

The second thrust should be the design and evaluation of training programs which will accelerate the development of battlefield expertise and visualization. This development should go on concurrently with the research being conducted under the first thrust described above. While not everything is known about what makes a commander an expert in the art of battle command, the present report has identified principles which are applicable to the battlefield domain. Training should incorporate the findings on Naturalistic Decision Making, the Recognition-Primed Problem Solving/Decision Model, and the Mental Simulation Model. The training programs should incorporate the principles identified by Kaempf and Klein (1993) and listed on pages 62 and 63 of this report.

Training must effectively compress the experiential learning curve. The key is to teach the developing commander the principles indicated above and to build an experience base through directed, manufactured, and vicarious experiences, without leaving experiential learning to chance. This will require the careful design of decision-centered scenarios and their implementation though simulations. Time and resources will never be available to give the developing commander the hundreds and thousands of exposures to richly-varied experiences which are commonly available for the development of expertise in other domains. In order to give a large number of "examples" in a short period of time, training may need to incorporate a large number of short "situational training exercises for the commander", incorporating relevant context and complexity but designed to meet specific training objectives. Objective measurement of performance and feedback to the "commander trainee" in After Action Reviews will accelerate learning. This feedback should relate the training experience he has just undergone to the principles underlying the art of battle command, as well as to traditional tactical and doctrinal principles. These short exercises would be followed by a smaller number of more complete simulations and, even fewer, field exercises. As information is obtained from the first thrust, described above, it can be incorporated in designing more effective training.

The Army may want to incorporate training in the "art of battle command" into specific courses. However, as the development of expertise is a long process in any domain, a broader examination of officer training and development may be desirable to insure that it is appropriate for the "soon-to-be" battlefield.

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APPENDIX A

ACRONYMS

AAR	After Action Review
ACUS-MSE	Army Common User-Mobile Subscriber Equipment
AFATDS	Automated Field Artillery Target Delivery System
AMLCD	Active Matrix Liquid Crystal Display
AN-VRC	Amplitude Node - Vehicular Radio Configuration
ARPA	Advanced Research Procurement Activity
ASAS	All Source Analysis System
AWACS	Airborne Warning and Control System
B2C2	Battalion Brigade Command and Control System
BCTP	Battle Command Training Program
BG	Brigadier General
BOS	Battlefield Operating System
C2	Command and Control
C3	Command, Control, and Communications
CAS3	Combined Arms Services Staff School
CGS	Common Ground Station
CGSC	Command and General Staff College
COA	Courses of Action
COMINT	Communications Intelligence
CP	Command Post
CPX	Command Post Exercise
CRT	Cathode Ray Tube
CTA	Cognitive Task Analysis
CTC	Combat Training Center
CTT	Commander's Tactical Terminal
DIS	Distributed Interactive Simulation
ELINT	Electronic Intelligence
FDC	Fire Direction Center
FIST	Fire Support Team
FSE	Fire Support Element
FTX	Field Training Exercise
GCS/RVT	Ground Control Station/Remote Vehicle Terminal
GPS	Global Positioning System
GRCS/U2	Guard Rail Common Sensor/
GSM	Ground Station Module
IPB	Intelligence Preparation of the Battlefield
HCI	Human Computer Interaction
HMD	Head Mounted Display
HUD	Heads Up Display
IDM	Improved Data Modem
IEW	Intelligence and Electronic Warfare
IMINT	Imagery Intelligence

IVIS	Intervehicular Information System
JSTARS	Joint Surveillance and Targeting System
LTG	Lieutenant General
MCS	Maneuver Control System
METT-T	Mission, Enemy, Terrain, Troops, Time Available
MG	Major General
MSE	Mobile Subscriber Equipment
NDM	Naturalistic Decision Making
NTC	National Training Center
OASD	Office of the Assistant Secretary of Defense
OC	Observer Controllers
OPLAN	Operations Plan
OPORD	Operations Order
OV-ID	Observer Vehicle - 1 Model D (Mohawk Airplane)
POSNAV	Positional Navigation
RPD	Recognition-Primed Decision Model
SCP	School for Command Preparation
SIGINT	Signal Intelligence
SIMNET	Simulation Network
SINCGARS	Single Channel Ground Air Radio System
SITMAP	Situation Map
SRC	Soldier Radio Computer
STX	Situational Training Exercise
TCDC	Tactical Commanders Development Course
TIBS	Tactical Information Broadcast System
TOC	Tactical Operations Center
TRADOC	U.S. Army Training and Doctrine Command
TRAP	Tactical Reconnaissance Airborne Platform
TRITAC	Tri-Service Tactical Area Communications
UAV	Unmanned Aerial Vehicle
VOB	Visualization of the Battlefield
X0	Executive Officer

APPENDIX B

This Appendix provides tables of characteristics for the communication and sensor systems described in chapter 2, according to the following factors:

- Volume. An estimation of the time it takes for a single transmission.
- Format. The form that a transmission takes, e.g., text, graphics, etc.
- Periodicity. A scaled value representing the frequency of transmission. Scale values are provided in the legend.
- Time/Location Specified. The type of time/location information specified in the transmission.
- Perishability. A scaled value indicating the degree to which the information retains its temporal relevance. Scale values are provided in the legend.
- Time Frame. Indicates whether the information is real time, near-real time, or historic.

Table 5 . Communications Systems Feeding Battle Command Functions at Brigade Level and Lower Through 1999

Battle Command Functions & Example Communication Messages Supporting Those Functions	System	Amount / Volume	Format / Structure	Period-icity	Time / Location Specified	Perish-ability	Time-Frame
Situation							
Enemy							
1. SPOTREPMSG	CNR - SINCGARS/ IVIS/SRC	<= 20 Secs	V or DA	VF	Current Enemy Sit / Loc / Act	Trans	RT to NRT
2. INTSUMMSG	ACUS - MSE (FAX)	2 / 3 pp <= 30 Secs	DA or DG	I	Enemy Sit / Loc /Act Last 24 hrs	Temp	Hist
Friendly							
10. SITREPMSG	CNR - SINCGARS / IVIS/SRC or ACUS - MSE (FAX) or ACUS - MCS/AMPS	> 20 Secs<=1 Min 2 / 3 pp <= 30 Secs 2 / 3 pp <= 30 Secs	V or DA DA or DG V or DA or DG	VF I	Current Friendly Sit / Loc / Act Within Last 1 hr to Last 24 hrs	Trans Temp	NRT Hist
Environment							
16. NBC1REP	CNR - SINCGARS/IVIS/SRC	<= 10 Secs	V or DA	I	Current Report-Enemy Chem Use	Trans	RT to NRT
Execution							
Cbt. Mnvr.							
24. MOVEORDMSG	CNR - SINCGARS/IVIS/SRC	<= 20 Secs	V or DA	F	Order to Move Pt A to Pt B Coord	Temp	Hist
27. CLOSEREPMSG	CNR - SINCGARS /IVIS/SRC	<= 20 Secs	V or DA	F	Report Due on Closing Pt B	Temp	Hist
28. AIRLIFTREQMSG	CNR - SINCGARS /IVIS/SRC or AM / IHFR / IVIS-IDM or ACUS - MSE / MCS	<=1 Min > 20 Secs<=1 Min 2 / 3 pp <= 30 Secs	V or DA V DA or DG	I	Friendly Airlift Support at Specific Time / Loc and # PAX or Material to be Carried to X Loc	Temp	Hist
Fires/FS							
29. FIRESPTREQMSG	AFATDS orSINCGARS	<= 15 Secs	V or DA	VF to F	Fr Req for FA or Naval Gun Fires	Trans	RT to NRT
30. AIRSUPREQMSG	AFATDS orSINCGARS or IVIS-AFATDS or ACUS-MSE/MCS	> 20 Secs<=1.0 Min > 20 Secs<=1.0 Min 1 pp @ <= 20 Sec	V DA or DG	VF to F	Fr Req for Close Air Support at Specific Time / Loc / En Tgt	Trans	RT to NRT
Air Def.							
36. A2C2COORDMSG	CNR - FM or SINCGARS or ACUS - MSE	> 30 Secs<=1.5 Min 2 / 3 pp @ <= 1 Min	V or DA V	VF to F	Fr Army Airspace Cmd & Cntrl Coordination Requirements	Trans / Temp to Lasting	NRT to Hist
MCMS							
42. MINEREPMSG	CNR - FM or SINCGARS	<= 1 Min	V or DA	F to I	Current Report-Enemy Mines Use	Temp to Lasting	NRT to Hist
Cmd/Cont							
51. FRAGOMSG	CNR - SINCGARS or IVIS or AM / IHFR / IVIS-IDM or ACUS - MSE / MCS	> 30 Secs <= 1 Min > 30 Secs <= 1.3 Min 1 / 2pp @ <= 40 Secs	V or DA V DA or DG DA DG	F to I	Establish or Change Current Situation, Mission, Execution, Logistics or Command & Signal	Temp to Lasting	NRT to Hist
Admin/Log							
Arm/Fuel							
52. CLV(AMMO)REQMSG	CNR - FM or SINCGARS or ACUS - MSE (FAX)	> 30 Secs <= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	I	Fr Req for Ammunition Supply or Resupply Support at Specific Time / Loc	Temp	Hist
Man							
55. FILLPERSREQMSG	CNR - FM or SINCGARS or ACUS - MSE (FAX)	> 30 Secs <= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA	I	Fr Req for Replacement Personnel at Specific Time / Loc	Lasting	Hist
Evacuate							
58. MEDEVACREQMSG	CNR - FM or SINCGARS or ACUS - MSE (FAX)	> 30 Secs <= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	F	Fr Req for Medical Evacuation Support at Specific Time / Loc	Trans	NRT
Fix							
59. CLIX(REPAIRPTS)REQMSG	CNR - FM or SINCGARS or ACUS - MSE (FAX)	> 30 Secs <= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	I	Fr Req for Repair Parts Resupply Support at Specific Time / Loc	Trans	NRT
Distribute							
60. CLI(RATION)REQMSG	CNR - FM or SINCGARS	> 30 Secs <= 1 Min	V or DA	I	Fr Req for Meals	Temp	Hist
65. AIRRESUPPLYREQMSG	or AM / IHFR / UHF or ACUS - MSE (FAX) - MCS	> 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs >15 Secs<=30 Secs 1 pp @ <= 20 Sec	V DA or DG DA DG	I	Fr Req for Aerial Resupply Support at Specific Time / Loc	Lasting	Hist
Reconstitute							
66. FILLUNITREQMSG	CNR - FM or SINCGARS or ACUS - MSE (FAX)	> 30 Secs <= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	I	Fr Req for Whole Unit Replacement in Reconstitution Required Situations	Lasting	Hist
Gains/Loss							
67. LOGSPOTREPMSG	CNR - FM or SINCGARS or ACUS - MSE (FAX)	> 30 Secs <= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	F	Report of Current Logistics Situation in the Command (Pers, Equip, Critical Classes of Supply	Temp	Hist

Legend

- Amount / Volume -- Estimation of how long it takes to transmit a single transmission in a range of seconds to minutes
- Format / Structure -- Form that a transmission takes, e.g., voice (V) or digital alphanumeric (DA), graphic (DG), imagry (DI)
- Periodicity -- Frequency of transmissions; scaled: Very Frequent (VF) is >= 15 per 24 hrs; Frequent (F) is 5 - 14 per 24 hrs; Infrequent (I) is<= 4 per 24 hrs
- Time / Location Specified -- States the type of time/location information specified in the message. E.g., "current friendly unit location / activity"
- Perishability -- Degree to which the information retains temporal relevance: Transient (Trans) is rapidly lost (short lifespan); Temporary (Temp) is retained limited time; Lasting (Last) is retained indefinitely
- Time Frame -- Is the information real time (RT), near-real time (NRT), or historical (Hist)

Table 6. Communications Systems Feeding Battle Command Functions at Brigade Level and Lower Through 2010

Battle Command Functions & Example Communication Messages Supporting Those Functions	System	Amount / Volume	Format / Structure	Periodicity	Time / Location Specified	Perishability	Time-Frame
Situation							
Enemy							
1. SPOTREPMSG	CNR - IVIS or IVIS / B2C2	<= 20 Secs	V or DA	VF	Current Enemy Sit / Loc / Act	Trans	RT to NRT
2. INTSUMMSG	ACUS - MCS / AMPS	2 / 3 pp <= 20 Secs	DA or DG	I	Enemy Sit / Loc /Act Last 24 hrs	Temp	Hist
Friendly							
10. SITREPMSG	CNR - IVIS or IVIS / B2C2 or ACUS - MCS/AMPS	<= 30 Secs 2 / 3 pp <= 20 Secs	V or DA DA or DG	VF I	Current Friendly Sit / Loc / Act Within Last 1 hr to Last 24 hrs	Trans Temp	NRT Hist
Environment							
16. NBC1REP	CNR - IVIS or IVIS / B2C2	<= 10 Secs	V or DA	I	Current Report-Enemy Chem Use	Trans	RT to NRT
Execution							
Cbt. Mnvr.							
24. MOVEORDMSG	CNR - IVIS or IVIS / B2C2	<= 20 Secs	V or DA	F	Order to Move Pt A to Pt B Coord	Temp	Hist
27. CLOSEREPMSG	CNR - IVIS or IVIS / B2C2	<= 10 Secs	V or DA	F	Report Due on Closing Pt B	Temp	Hist
28. AIRLIFTREQMSG	CNR - IVIS or IVIS / B2C2 or IVIS-IDM or ACUS-MCS /AMPS	<= 30 Secs <= 30 Secs 2 / 3 pp <= 20 Secs	V or DA V DA or DG	I	Friendly Airlift Support at Specific Time / Loc and # PAX or Material to be Carried to X Loc	Temp	Hist
Fires/FS							
29. FIRESPTREQMSG	AFATDS or IVIS	<= 10 Secs	V or DA	VF to F	Fr Req for FA or Naval Gun Fires	Trans	RT to NRT
30. AIRSUPREQMSG	AFATDS or IVIS or IVIS / AFATDS	<= 30 Secs <= 30 Secs	V DA or DG	VF to F	Fr Req for Close Air Support at Specific Time / Loc / En Tgt	Trans	RT to NRT
Air Def.							
36. A2C2COORDMSG	CNR - FM or SINCGARS or ACUS - MSE	> 30 Secs<=1.5 Min 2 / 3 pp @ <= 1 Min	V or DA DA or DG	VF to F	Fr Army Airspace Cmd & Cntrl Coordination Requirements	Trans / Temp to Lasting	NRT to Hist
MCMS							
42. MINEREPMSG	CNR - IVIS or IVIS / B2C2	<= 20 Secs	V or DA	F to I	Current Report-Enemy Mines Use	Temp to Lasting	NRT to Hist
Cmd/Cont							
51. FRAGOMSG	CNR - IVIS or IVIS / B2C2 or IVIS-IDM or ACUS-MCS /AMPS	<= 30 Secs <= 30 Secs 2 / 3 pp <= 20 Secs	V or DA V DA or DG	F to I	Establish or Change Current Situation, Mission, Execution, Logistics or Command & Signal	Temp to Lasting	NRT to Hist
Admin/Log							
Arm/Fuel							
52. CLV(AMMO)REQMSG	CNR - SINCGARS or ACUS - MSE/ MCS	<= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	I	Fr Req for Ammunition Supply or Resupply Support at Specific Time / Loc	Temp	Hist
Man							
55. FILLPERSREQMSG	CNR - SINCGARS or ACUS - MSE/MCS	<= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA	I	Fr Req for Replacement Personnel at Specific Time / Loc	Lasting	Hist
Evacuate							
58. MEDEVACREQMSG	CNR - SINCGARS or ACUS - MSE/mcs	<= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	F	Fr Req for Medical Evacuation Support at Specific Time / Loc	Trans	NRT
Fix							
59. CLIX(REPAIRPTS)REQMSG	CNR - SINCGARS or ACUS - MSE/MCS	<= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	I	Fr Req for Repair Parts Resupply Support at Specific Time / Loc	Trans	NRT
Distribute							
60. CLI(RATION)REQMSG	CNR - SINCGARS	<= 1 Min	V or DA	I	Fr Req for Meals	Temp	Hist
65. AIRRESUPPLYREQMSG	CNR - SINCGARS or IHFR or ACUS - MSE/MCS	> 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs 1 pp @ <= 20 Sec	V DA or DG DA DG	I	Fr Req for Aerial Resupply Support at Specific Time / Loc	Lasting	Hist
Reconstitute							
66. FILLUNITREQMSG	CNR - SINCGARS or ACUS - MSE/MCS	<= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	I	Fr Req for Whole Unit Replacement in Reconstitution Required Situations	Lasting	Hist
Gains/Loss							
67. LOGSPOTREPMSG	CNR - SINCGARS or ACUS - MSE/MCS	<= 1 Min > 30 Secs <= 1 Min 1 / 2pp @ <= 40 Secs	V or DA DA DG	F	Report of Current Logistics Situation in the Command (Pers, Equip, Critical Classes of Supply	Temp	Hist

Legend

- Amount / Volume – Estimation of how long it takes to transmit a single transmission in a range of seconds to minutes
- Format / Structure – Form that a transmission takes, e.g., voice (V) or digital alphanumeric (DA), graphic (DG), imagry (DI)
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- Perishability – Degree to which the information retains temporal relevance: Transient (Trans) is rapidly lost (short lifespan); Temporary (Temp) is retained limited time; Lasting (Last) is retained indefinitely
- Time Frame – Is the information real time (RT), near-real time (NRT), or historical (Hist)

Table 7 . Sensor Systems Feeding Battle Command Funcations and Required Communications at Brigade Level and Lower -- 1993/2010

	Battle Command Functions & Sensor Systems Supporting Those Functions	System	Amount / Volume	Format / Structure	Periodicity	Time / Location Specified	Perish-ability	Time-Frame
	1999							
BDE	Situation, Execution	CTT	<= 20 Secs.	DA/DG/DI	VF	Current Enemy Situation	Trans	RT to NRT
BDE	Situation, Execution	GSM	<= 1.0 Min	DI/DG	VF	Current Enemy Situation	Lasting	RT w/ Hist.
BDE	Situation, Execution	UAV-GCS/RVT	Continuous	Video	Continuous	Current Enemy Situation	Lasting	RT w/ Hist.
BN	Situation, Execution	UAV/RVT	Continuous	Video	Continuous	Current Enemy Situation	Lasting	RT w/ Hist.
	2010							
BDE	Situation, Execution	CTT	<= 20 Secs.	DA/DG/DI	VF	Current Enemy Situation	Trans	RT to NRT
BDE	Situation, Execution	CGS	<= 1.0 Min	DI/DG	VF	Current Enemy Situation	Lasting	RT w/ Hist.
BDE	Situation, Execution	UAV-GCS/RVT	Continuous	Video	Continuous	Current Enemy Situation	Lasting	RT w/ Hist.
BN	Situation, Execution	UAV/RVT	Continuous	Video	Continuous	Current Enemy Situation	Lasting	RT w/ Hist.

Legend

- Amount / Volume -- Estimation of how long it takes to transmit a single transmission in a range of seconds to minutes
- Format / Structure -- Form that a transmission takes, e.g., voice (V) or digital alphanumeric (DA), graphic (DG), imagry (DI)
- Periodicity -- Frequency of transmissions; scaled: Very Frequent (VF) is >= 15 per 24 hrs; Frequent (F) is 5 - 14 per 24 hrs; Infrequent (I) is <= 4 per 24 hrs
- Time / Location Specified -- States the type of time/location information specified in the message. E.g., "current friendly unit location / activity"
- Perishability -- Degree to which the information retains temporal relevance: Transient (Trans) is rapidly lost (short lifespan); Temporary (Temp) is retained limited time; Lasting (Last) is retained indefinitely
- Time Frame -- Is the information real time (RT), near-real time (NRT), or historical (Hist)

APPENDIX C

Study A

Purpose: To investigate the information used in the development of VoB and/or decision making and the extent to which it differs across levels of expertise. In addition to investigating differences across levels of expertise, this may help to identify information that "closes" decision making (a la figure-ground context and standard symbology discussion).

Subjects: Junior and Senior Officers (Note: level of expertise will require further explication than this. Something like field experience should be considered.)

Independent Variables: Information Attributes, including, but not limited to:

Content: Red situation, Blue situation, terrain/environmental factors.

Format: Text, graphic, video.

Source: Situation report, sensor data, "fused" data.

Quality: Some continuum that gets at mission, corrupt, unclear, or incomplete information.

Veracity: Some continuum that includes deceptive or misleading information.

Dependent Variables:

The proportion of each type of information used in developing VoB/decision making.

Accuracy (reflecting actual events) of VoB (possibly determined by expert judges).

Possible Venues: Soldier-in-the-loop simupation
CTC archival data
Janus simulations

Study B

Purpose: To investigate the changes in VoB over the course of a battle and how that differs across levels of expertise. Subjects would essentially predict the outcome of a series of battles. Given (experimenter-engineered) changes in events, modifications to the initial visualization would be required. We would expect experts to be more facile in their response to battlefield changes, making changes to their predictions, as necessary. Additionally, we might be able to identify the type/amount of information that commanders use as "key reads" to alter their predictions. It might also be possible to investigate the effects of time pressure on this process.

Subjects: Junior and Senior Officers (see previous note)

Independent Variables:

Stage (or course) of battle

Time constraint (if desired): Low, med, high

Information attributes: See Study A

Dependent Variables:

Life span of the VoB, that is, how long does the "current" VoB remain accurate (reflect actual events).

Number of VoB changes

Key reads upon which changes in VoB are predicted.

Possible Venues:
Soldier-in-the-loop simulation
Carefully selected CTC archival data
(data that ensure circumstances leading to a required change in VoB).
Carefully selected Janus simulations
(data that ensure circumstances leading to a required change in VoB).

Study C

Purpose: To investigate the different strategies applied and information used across the different levels (types of problems) of the RPD model. This will involve constructing scenarios that equate to the different levels of the RPD and have subjects make decisions/predictions. This is likely a "think aloud" method as we will want to compare strategies and information across the scenarios and across level of expertise.

Subjects: Senior and Junior Officers

Independent Variables:

Scenario: 1-4 (corresponds to RPD levels)

Information attributes: See Study A

Dependent Variables:

Strategies/methods
Information
"Correctness" of decision

Possible Venues: Soldier-in-the-loop simulation
Carefully selected CTC archival data (to meet RPD level criteria).
Carefully selected Janus simulations (to meet RPD level criteria).